REPORT
Designation Dnr TSG 2023-8756
February 2026

Improved standard for testing of composite brake blocks for winter conditions – testing at the Becorit winter brake bench of two K type brake blocks

Väg och järnväg/ Department of Road and Railways
Enhet Spårtrafik/Rail Unit

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1 Foreword

The purpose of this project is to be able to increase and permanently stabilize the safety when running freight trains equipped with composite brake blocks during Nordic winter conditions. The goal of the project is to propose a supplement to the existing test procedure for approval of composite brake blocks. The core intention with the proposal is to reflect the real conditions in the test procedure as much as possible. The predominant effort has been to concretely identify factors that influence the braking capability and transform these conclusions into test specifications in order to compose a better and more reliable test procedure that can duplicate and reflect the real environment factors.

A second, and consecutive, objective is to reduce or even remove the operational adaptations that railway companies are forced to introduce as a result of vehicles being equipped with composite brake blocks and thereby maintain a functional and cost-effective capacity utilisation. With more reliable brake blocks, operational safety can thus be improved.

The Project has in a first report, see Annex 1, analysed and examined in detail lab- and field test information from documents from UIC, ERA, EN standards, Green Cargo, Transportstyrelsen and from the open literature. The report also considered winter braking rules/guidelines used by Green Cargo and Hector Rail, two of Sweden’s freight companies, and outlines the winter conditions in which braking performance problems occur. The report also proposed a modified winter test procedure to be conducted on the air-conditioned Becorit test bench in Recklinghausen in order to create better understanding.

The present report details the tests that were performed in late summer 2025 by Becorit. Test results from the test bench runs strongly indicates that there is a significant discrepancy comparing to the programme in vigour when altering some of the test parameters, to ones that reflect the conditions during real operation under winter conditions.

Following the test run results analysis the Project did observe relevant additional need for further investigation of wheel and brake block temperatures at braking, investigated using numerical simulations and measured brake block thermal properties. Those results will eventually accompany and complement the core project design and should be regarded as complementary observations determining a fundamental condition affecting the braking capacity during usage under winter conditions.

The Project has firmly identified near future considerations to adapt and alter the relevant parameters, in the test programme such as enhancing the reliability towards the capability of braking blocks, thus increasing safety, simplifying the undertaking of train companies as for the train drivers on the track, and strengthening the attractiveness and competitiveness of the railway.

Finally, I wish to sincerely thank the project experts, Tore Vernersson, Petter Hydén and Lars Fehrlund, for their excellence of mind, competence and commitment throughout the whole work period, never avoiding the sometimes troublesome conditions and ever supporting each other and me to reach the goal and always looking ahead and acting towards a safe and viable railway.

I also thank Trafikverket, especially Matthias Asplund and his colleagues, who funded this project and have shown patience, tolerance and understanding.

Of course, the Project thanks all personnel at Becorit, Recklinghausen, certainly Daniel Rabiega, Frank Keller and Jan Füser, who assisted and supported us before and during the test runs and overcame the sudden twitches of fate with elegance.

Borlänge December 2025

Sten-Olov Södergård
Internationell samordnare järnväg /International affairs/LL M

2 Summary

The Swedish Transport Agency aims at providing a basis for an improved testing procedure for composite brake blocks to mitigate today's situation with occasionally and suddenly degraded braking performance in certain, but frequently or probably occurring, winter conditions. Such degraded braking performance has been reported in Sweden, Finland and Norway. In a first report, the background on today´s standard for winter testing of composite blocks was provided along with a survey on literature focusing on winter braking performance with emphasis on influencing parameters.

In this, complete, report, the winter braking tests performed at the Becorit winter brake bench for two weeks are described and the results are presented and analysed in detail. The procedure of developing the testing scheme was based on discussions between the braking experts at Becorit (mainly Daniel Rabiega, Frank Keller and Jan Füser) and the experts representing Transportstyrelsen. Testing was performed using two UIC 541-4 certified brake block types, namely the organic composite J822 and the sintered C333. The selected blocks are two types that run in homogeneous block trains[1], unladen or laden, where there are good and bad experiences of their braking performance under winter conditions.

Some main differences as compared to UIC 541-4 certification tests are that

1) The tests are performed at lower ambient temperatures, between -15 ºC and -20 ºC, instead of at temperatures down to -7 ºC. The wheel temperature at brake application is -10 ºC, instead of -3 ºC or -4 ºC, which better corresponds to temperatures when winter braking problems occurs.
2) Tests are performed at an axle load that corresponds to a typical unladen wagon, 4,8 ton, which is similar to UIC 541-5 which has 5 tons axle load.
3) Testing was performed at 1 x Bgu brake block configuration since this is the most common set-up on freight wagons with K-blocks. Testing according to UIC 541-4 winter tests is performed with 2 x Bgu configuration.
4) Application brake force per brake shoe holder that corresponds to a typical unladen wagon which is 6,3 kN for C333 and 7,5 kN for J822. UIC 541-4 uses 2 x 4,5 kN, total 9 kN. The lower total application force is chosen since the experience is that winter braking problems are worse for light wagons with corresponding low application forces.
5) Tests are performed under snow conditions as in UIC 541-4, but also for the situation with an initial ice layer deposited on the brake block friction surface, which corresponds to a scenario experienced in real operation.
6) After each actual winter tests stop braking, it was chosen to have a minor condition braking from 50 km/h instead of 120 km/h as in UIC 541-4 since this is not always possible during normal operation.
7) Winter testing as of UIC 541-4 is, according to Becorit staff, performed at a water flow of 12 l/h to the snow nozzle which is standard procedure. This flow was reduced at some tests to 6 l/h and even 3 l/h.

The main findings are that:

1) For the situation that ice is deposited on the brake block contact surface:

[1] All wagons are loaded or empty, and with the same brake system including type of brake block.

a) The braking distance is substantially prolonged for both brake blocks. During the time for which there is no actual direct contact between friction material and wheel tread the friction stays low, between 0,005 and 0,03. No major difference in performance can be found between the two brake block types during this time.

b) At the instant when the coefficient of friction increases to a value that indicates direct contact between friction material and wheel tread, there is for the sintered material C333 a short delay until a high coefficient of friction is reached, whereas for the organic J822 the time is much longer and the resulting coefficient of friction at the end of this transition is generally lower.

c) This indicates that for the sintered material, the entire contact surface clears of ice quickly once in contact with the wheel, while for the organic material, ice is removed more slowly, potentially leaving ice on the brake block friction surface after braking.

2) For the situation that snow is applied before and during brake application:

a) Snow is deposit on the wheel tread, and most likely on the friction surface of the brake blocks. However, at initiation of braking snow is trapped between brake blocks and wheel tread.

b) Brake block J822 shows substantially prolonged braking distances, with clear history effects with a prolongation of brake distance after each brake cycle, compared to previous cycle, whereas block C333 shows a minor increase in early braking distance tests (that are within a 15 % prolongation required for approval in UIC 541-4), but that show history effects after several stops at 6,3 kN.

c) Short braking distances are found for block C333 at both 100 km/h and 70 km/h when performing brake tests with enhanced condition braking from 120 km/h between snow tests (as used in UIC 541-4) instead of the regularly used 50 km/h.

3) When braking from 70 km/h the braking distances are extremely prolonged both with an ice layer on the friction surface on the block and with snow application.

4) There are indications that higher braking forces are beneficial for winter braking performance, both for braking with ice on brake blocks and for snow conditions.

5) Thermal simulations of train brake conditioning were performed that could assist in explaining the presence of ice on the contact surfaces of J822 brake blocks in service, and that no similar effect can be found on brake blocks of type C333, which normally are ice-free in real operation.

This report clearly points out some braking performance deficiencies that can manifest under certain winter related conditions. These winter braking deficiencies, pinpointed by the winter brake bench tests, are related to actual observed winter problems of Swedish freight companies.

The findings presented in this report—comprising the main document, annex, and appendices—draw on reviews, analyses, experimental testing, and numerical simulations. Together, they highlight a continued need for focused work to ensure reliable and safe winter braking properties. This project represents another step forward, building on the foundation laid by previous UIC-led initiatives. Looking ahead, the project hopes that additional partners will join in advancing the pursuit of safe and dependable winter braking capability. Future efforts are anticipated not only in the form of further testing and analysis, but also in the refinement of standards and relevant legal frameworks.

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4 Background and aim

4.1 Introduction to the project topic

Railway undertakings, as on their part also infrastructure managers in Sweden, and also in neighbouring countries, have experienced inadequate and unreliable braking capability of composite brake blocks, thus endangered the railway safety and limited and reduced the competitiveness of the railway. Measures, operational and capacity wise, have been necessary to keep the safety to an acceptable level, even to the extent that these led to that individual trains have had to be cancelled.

4.2 Problem statement and purpose; scope

To a user it is problematic that some of the certified brake blocks actually in operation show evidence of not performing in accordance with the test results implied by winter test certification. The Project has therefore questioned if the existing test procedure for approval of composite brake blocks consists of necessary relevant specifications related to the winter conditions under which the braking block is supposed to be used. The core intention with the project is to study if there is need to complete or adjust the test procedure so that the test programme reflects the real conditions as much as possible.

4.3 Delimitations

To understand the work and eventually the conclusions based on the results and analysis it is necessary to declare the overall intentions and the scope delimitations.

The project aims at studying the relevancy of certain specifications of the test procedure related to winter conditions and eventually show valid proposals to complete the test procedure through improved compliance with the real winter conditions and corresponding to the actual performance on the track.

The selected blocks are two types that run in homogeneous block trains[2], unladen or laden, where there are good and bad experiences of their braking performance under winter conditions.

Further, the Project has found that the choice of the user is guided by a complex mix of factors. These consist in considerations regarding, e.g., general performance (365-day usage, all weather conditions), purchase cost, maintenance conditions (handling costs and complexity), wear properties (both on the block itself as on the wheel), accessibility.

The purpose of this project and the tests is not to reject or disqualify previous certifications or tests.

Further, it is not within the purpose of the project to suggest a new test procedure related to winter conditions, but to present a basis for further investigations of altered set of specifications.

[2] All wagons in the trains are loaded or empty, and with the same brake system including type of brake block.

5 Test set-up

The instrumentation at testing was the traditional one, meaning measurement of pneumatic pressure, brake normal force, brake torque and testing speed. Regarding the inflow of air, the airspeed and temperature was measured. Note that the measured airspeed mainly was used for monitoring of the refrigeration unit: if it got too low a complete deicing was required, which took about 12 h. For the outflow of air, only temperature was measured.

Data signals were acquired by two separate data acquisition systems: one linked directly to the brake bench control system, which saves data during stops only, and the other an additional stand-alone system that was measuring continuously during entire testing. The information from the brake control system was used for on-site assessment of braking performance in the form of stopping distances, whereas the data from the stand-alone system was used for monitoring all other data including measured temperatures in wheels and brake blocks. It can be noted that the braking distances provided by the brake control system were preliminary, meaning that they deviate somewhat from final values on braking distances given in the present report, that adhere to the UIC-definitions on braking distances.

The wheel used for testing had running diameter 888 mm, which meant that it was semi-worn. The wheel[3] is in new condition 920 mm and in fully worn condition 840 mm.

6 Winter testing procedure and test parameters

Somewhat different braking parameters were used for the two types of brake blocks, J822 [Ref. 7] [Ref. 8] and C333 [Ref. 6], and they are for this reason given separately below. The choice of testing parameters was based on a preliminary plan written by the Transportstyrelsen expert group prior to testing, after early discussions with Becorit. However, because the plan was drafted without knowing the actual testing facilities or procedures, it was revised at on-site discussions during winter tests on block J822, based on joint decisions by Becorit staff and Transportstyrelsen representatives. The testing plan of block C333 largely followed the one of J822, but with some additional parametric surveys that could be performed during the few last days of testing.

Testing was first performed using blocks J822 (winter testing during first week of September) and after that blocks C333 (tested during second week of October). The reason for not performing tests on C333 directly after testing of J822 was malfunctioning of a communications module that facilitate control of the cooling system. Upon replacement and reprogramming of the module, testing of C333 commenced immediately.

[3] The test wheel was of type “Lucchini tiefgewölbtes Rad, LK ø888 mm, R7”, Internal Becorit No A561.

6.1 The Becorit test bench

The tests were performed in the Becorit test bench, see

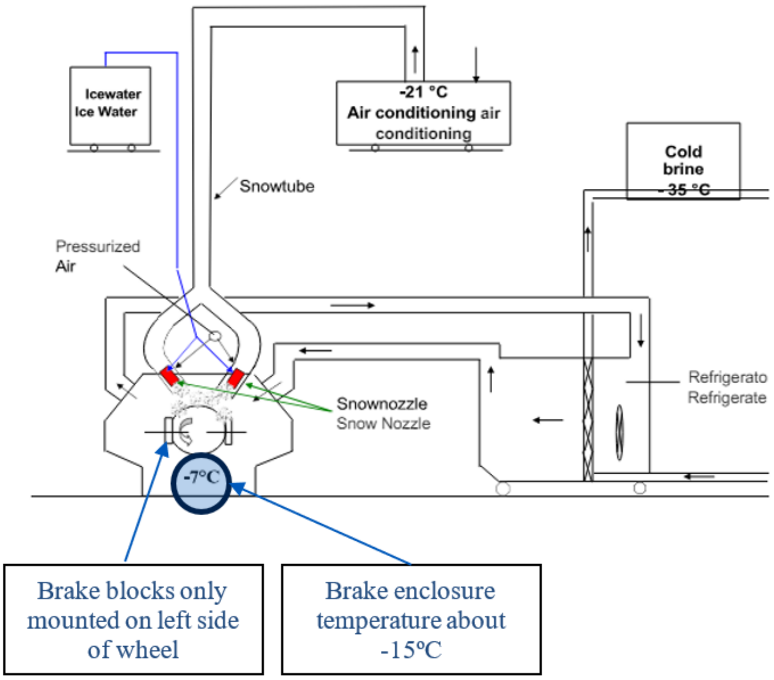


Figure 1.

The Becorit winter brake bench was developed in collaboration with UIC and is described in the report B 126 / RP 37, "Braking Questions Winter properties of composite brake blocks" from 2010 [Ref. 9].

The test bench fulfils the requirements in IRS 50548 [Ref. 5].

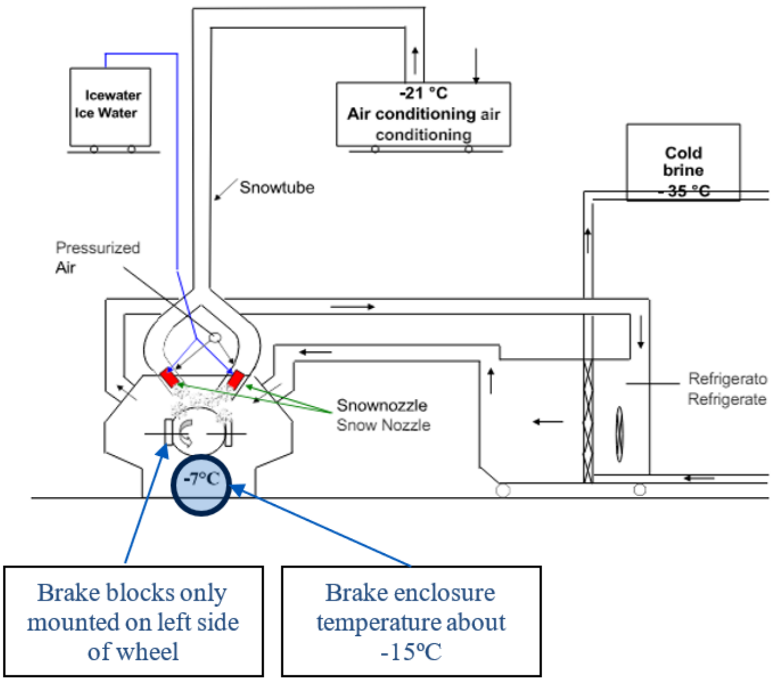


Figure 1. Schematic representation of the Becorit test bench [Ref. 9], with minor adaptions indicated at bottom. Note that testing was performed at 1 x Bgu block configuration.

6.2 Brake blocks included in test J822 and C333

The brake blocks that were tested were supplied by Transportstyrelsen. Four brake blocks were supplied by each type, out of which two of each type were used at tests. The brake block types that were tested were

- organic, high friction brake block, K-block, J822, and
- sintered, high friction brake block, K-block, C333.

Length of brake block is 250 mm since configuration is 1 x Bgu, see section 6.3.

Figure 2. Photos of brake blocks: J822 (top) and C333 (bottom), with embedded thermocouples in one brake block, and a small handle to be able to easily mount and dismount the brake block. Photos are taken after the tests.

6.3 Configuration 1 x Bgu

The configuration 1 x Bgu is used instead of 2 x Bgu as in UIC 541-4 [Ref. 4], Test Program, A5_a.

It shall be noted that 1 x Bgu (or 1 x Bg) is today the most common configuration for composite brake K blocks. It shall be noted that when the test program of UIC 541-4 was designed 2 x Bgu were common.

The operational experience from Sweden is based on 1 x Bgu.

6.4 Application force per brake block holder and axle load

Operational experience clearly shows that the occurrence of prolonged braking distances at low temperatures and snow drift occurs for trains with unladen wagons. To test in the same conditions was

- the application force per brake block holder and
- the axle load

chosen to be the same as in the cases for the two brake systems with extensive operational experience in Sweden.

Axle load was therefore 4,8 tons and the application force per brake block holder was set to

- 7,5 kN for the brake block J822 and
- 6,3 kN for the brake block C333.

The chosen application forces per brake block holder and the axle load correspond to unladen wagons where there is extensive operational experience. In unladen state is the brake percentage slightly above 100 %[4].

In addition, there were a few tests, where the brake block force was increased, to study the influence of the application force per brake block holder.

The UIC 541-4 [Ref. 4], Test Program A5-a, in cold and snow conditions, is performed with

- application force per brake block holder 4,5 kN, but since the configuration is 2 x Bgu it is in summary 9 kN, i.e., 2 x 4,5 kN, and
- axle load 5,0 ton.

6.5 Speed at brake application

Freight trains in Sweden are mainly operated with v_{max} 100 km/h, but v_{max} between 70 and 120 km/h occurs for regular trains.

However, in typical operations, independent of v_{max} of the train, braking is commonly applied at lower speed than v_{max}. Based on operational experience we have identified that 70 km/h is a common speed for brake initiation.

It shall be noted that operating experience indicates a slightly higher frequency of occurrence of disturbances when a brake is initiated at lower speed (than 100 and 120 km/h).

The UIC 541-4 [Ref. 4], Test Program A5_a, uses a brake initiation speed of 100 and 120 km/h. To have comparable results and still see the influence of brake initiation speed, the tests are performed at 100 and 70 km/h.

It shall be noted that there is an experience of disturbances at low temperature and snowdrift with CBBs in low-speed operation and at standstill. Low speed operation means here typically speed up to 30 km/h, for example shunting operation with braked wagons or operation within a station to prepare a train for departure. This is not included in this test program.

6.6 Ambient temperature at tests

Experience shows that disturbances at low temperature and snowdrift with CBBs typically occurs at ambient temperatures $\lesssim$ -7 °C, see Annex 1. However, there is an uncertainty in temperature reports from operation since the temperature varies along the line. A typical ambient temperature is between -10 and -20 °C when disturbances occur in operation.

The test bench has broad limits in cooling capacity. Temperature is measured at incoming and outgoing air. It is judged that similar temperatures result inside the testing enclosure, or slightly higher than outgoing (and incoming air). Regarding ambient temperature at the winter tests, it was debated what a relevant testing temperature would be, with knowledge of that

1) the refrigeration unit can produce very low temperatures, but that
2) the use of lower temperatures would mean more frequent, i.e. time-consuming deicing of the refrigeration unit because of build-up of ice on the heat exchanger.

The latter item was considered a troubling point and there was a limited experience on testing at very low temperatures.

The temperature is therefore specified as within the range of -15 °C to -20 °C for the incoming air.

[4] Allowed brake percentage in empty/unladen state, λ, is 100 % < λ < 125 %

Previous experience from Becorit shows that it was important that the brake bench was cooled for at least 12 hrs before starting the test to ensure that all components had reached the testing temperature.

UIC 541-4 [Ref. 4], Test Program, A5_a, use higher temperatures. The test chamber has -7 °C, 12 hrs before and at start of test.

6.7 Temperature measurements in brake block and wheel

Temperature in brake block shall be measured in 10 mm under the friction surface and in the middle of a brake block.

Temperature in wheel were measured using embedded thermocouples in the wheel rim. These were positioned 120 degrees apart at given distances from the wheel flange face: T1 was 55 mm, T2 85 mm and T3 105 mm. The thermoelements are embedded 5 mm under the wheel tread[5].

The purpose with having embedded thermocouples in the wheel and at different depths from the friction surface in a brake block is to establish the temperature gradient in the brake block. Based on this temperature variation during and after a brake cycle can the temperature at the brake block friction surface and the wheel tread be estimated. The temperature variation at the brake block friction surface and the wheel tread can then be used for evaluating different wagon exercising methods for the different brake blocks. The purpose is to understand the mechanism for how the ice layers are created and identify the most efficient way to exercise the two types of brake blocks.

The mean temperature in the wheel is also used as trigger for a brake cycle, see section 6.10 below.

6.8 Ice layer on block

Experience from operation is that a thin ice layer can be identified typically on brake block type J822. It is judged that this ice layer is created from snow that melts on the warm wheel and is sprayed on to the friction surface. The purpose of this testing is to re-create a situation similar to the one found in real operation.

The UIC 541-4 [Ref. 4], Test Program, A5_a, does not include such a test.

The procedure for braking with ice on the brake blocks meant quick spraying of the brake blocks with cold water having a temperature of approximately 0 ºC to +4 ºC, after which the ice was left to cure and harden for 1 minute, after which it was sprayed again. This was repeated so that the blocks were sprayed 6 times. Actual time of each spray application was approximately 1 second per brake block, see photo of block sprayed with water in Figure 3.

The thin ice layer was not measured at testing, but it was approximately ≲ 0,5 mm thick, see Figure 4, which was judged as similar to a typical ice layer in real operation.

[5] See IRS-50548:2022 [Ref. 5], Ed 2, Fig. 23.

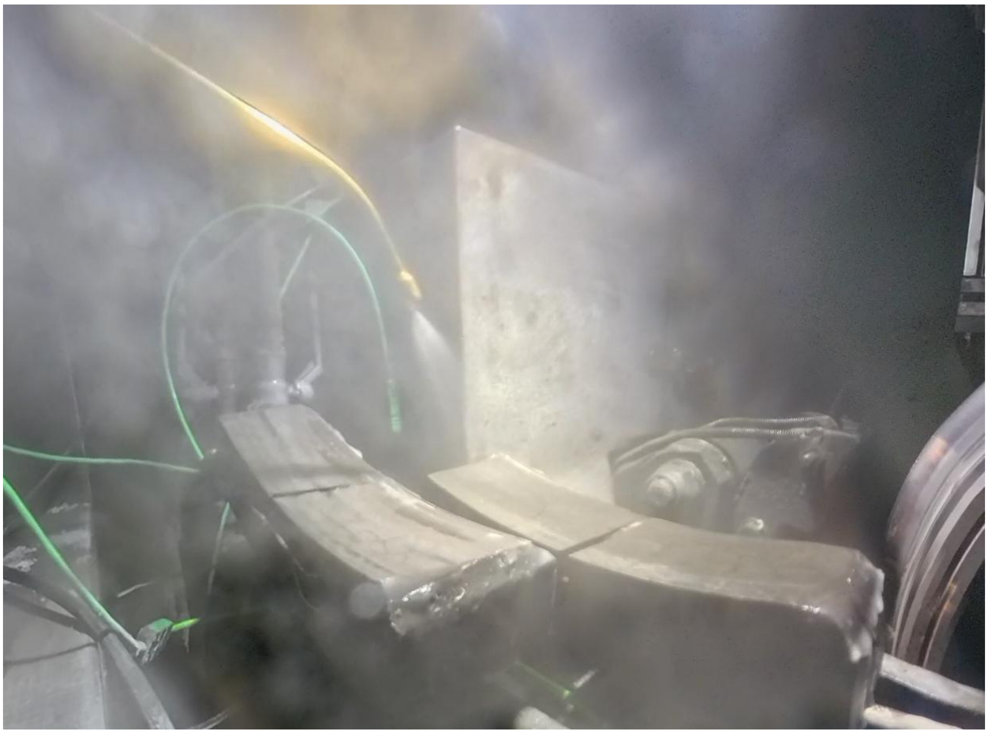


Figure 3 Photo taken during water spraying of J822 brake blocks.

Figure 4. Brake block J822 with a thin layer of ice on the friction surface

6.9 Snow

The UIC 541-4 [Ref. 4], Test Program, A5_a, includes tests with snow. The snow is here applied in the same way but at lower temperature, and testing is performed with different forces, etc.

Braking with snow application according to UIC 541-4 was generally performed at 12 l/h water to the nozzles. This was later reduced at some tests, see results section 9.

The purpose is to have comparable results, but with different parameters, as in UIC 541-4, Test Program, A5_a.

6.10 Triggering point for a brake cycle

The test shall be performed at slightly lower temperature than UIC 541-4 [Ref. 4], Test Program, A5_a, therefore was the trigger point, when a new brake cycle starts, set to -10 ºC as mean temperature in the wheel, instead of -3 to -4 ºC.

Note that temperature in brake block was not used as a trigger point.

6.11 Brake cycle and sequence

Brake cycles are in principle the same as in UIC 541-4 [Ref. 4], Test Program, A5_a, but there are deviations, see section 9.

6.12 Condition brake

After a stop brake cycle with ice on the block or with snow, a condition stop brake cycle from 50 km/h was foreseen. The purpose was to have a brake cycle that corresponds to real operation and not the strong stop braking from 120 km/h which is specified in UIC 541-4 [Ref. 4], Test Program, A5_a.

It can here be noted that the increase in temperatures due to brake conditioning depends on the kinetic energy of the stop. For a given axle load, a stop from 120 km/h has 44 % more energy than a stop from 100 km/h, whereas a stop from 50 km/h merely has 17 % of the one at 120 km/h. This chosen condition brake cycle is significantly less powerful than prescribed in UIC 541-4, Test Program, A5_a.

In addition to the planned stop after ice / snow tests, it was occasionally necessary to have an additional condition cycle for both J822 and C333, if so, prompted because of too low testing temperatures in the wheel[6]. The J822 brake blocks also occasionally needed to be taken out of the test chamber for deicing with hot air. Information on the latter has been added in the results section, 9.

It shall be noted that additional measures do occur, if necessary, also in real operation, but then performed as several brake cycles repeated from safe speed (not 120 km/h as in UIC 541-4) or as repeated warm braking with locomotive traction.

Note that the condition stop brake cycle, performed without snow or additional ice on the block, shall not be confused with exercising of brake blocks in normal operation. The condition stop brake cycle is performed immediately after the snow or iced, test brake cycle.

6.13 Bedding in

The bedding in is the same as in the UIC 541-4 [Ref. 4], Test Program, A5_a.

It could be debated that, in real operation, the brake blocks have average wear and thickness.

As a sidenote, it was found that about 500 stops were required to bed in the sintered C333 brake blocks and that about 60 stops were required for the organic J822 blocks. This even though the brake blocks were machined to roughly fit the test wheel diameter, Ø888 mm. The same parameters were used for both brake blocks during bedding in; 7,5 ton axle load, 100 km/h, 30 kN brake force.

[6] Too low wheel temperature gives problem with the triggering of a winter brake test.

6.14 Dry brake application, warm, is excluded

Since this is a test campaign where we assess two different brake block types in winter conditions with the aim to only *compare* performance, not certify or approve a brake block, this was excluded compared to UIC 541-4 [Ref. 4], Test Program, A5_a.

6.15 Test parameters at bench tests

Parameters for the test are specified in sub-sections below.

6.15.1 Parameters used for organic J822

The parameters used at testing

- at reference conditions, here considered as braking distances under cold conditions[7], see Table 1,
- ice conditions, see Table 2, and
- snow conditions, see Table 3.

Table 1 Parameters used at testing of brake block J822 under reference conditions

Brake stop number	Speed [km/h]	Force [kN]	Comment
1, 3, 5, 7, 9 ,11	100	7,5	
2, 4, 6, 8, 10, 12	70	7,5	

Table 2 Parameters used at testing of brake block J822 under ice conditions

Brake stop number	Speed [km/h]	Force [kN]	Condition Comment
1, 3, 5, 7, 9 ,11	100	7,5	Deicing of blocks after stop 5
2, 4, 6, 8, 10, 12	70	7,5	
13	100	9.3	

Table 3 Parameters used at testing of brake block J822 under snow conditions

Brake stop number	Speed [km/h]	Force [kN]	Comment
1, 3	100	7,5	Water flow 12 l/h
2, 4	70	7,5	Water flow 12 l/h
5, 7	100	7,5	Water flow 6 l/h
6, 8	70	7,5	Water flow 6 l/h Deicing of blocks after stop 8
9, 11	100	7,5	Water flow 3 l/h
10, 12	70	7,5	Water flow 3 l/h

[7] Enclosure temperature -15 °C

6.15.2 Parameters used for organic C333

Initial testing at reference conditions of brake block C333 involved finding a suitable braking force that could give a braking distance similar to the one of J822 at reference conditions. For this reason, the force was lowered in two steps from the initial magnitude. In the end, the third force magnitude was considered representative since it corresponds to application force per brake block holder and axle load for an unladen wagon where there is extensive operational experience. An additional benefit of having reference brake results at three force levels was that it allowed for estimation of braking distance at reference condition (cold and dry) for other force levels.

Table 4 Parameters used at testing of brake block C333 during search for proper reference conditions

Brake stop number	Speed [km/h]	Force [kN]	Comment
1, 3, 5	100	7,0	
2, 4	70	7,0	
6, 8	100	6,6	
7, 9	70	6,6	
10, 12, 14, 16	100	6,3	Force giving similar braking distance as J822
11, 13, 15	70	6,3	

Table 5 Parameters used at testing of brake block C333 under reference conditions

Brake stop number	Speed [km/h]	Force [kN]	Comment
1, 3, 5, 7, 9 ,11	100	6,3	
2, 4, 6, 8, 10, 12	70	6,3	

Table 6 Parameters used at testing of brake block C333 under ice conditions

Brake stop number	Speed [km/h]	Force [kN]	Comment
1, 3, 5, 7	100	6,3	Leaking snow cannon at test 1
2, 4, 6, 8	70	6,3	Leaking snow cannon at test 2
9, 11	100	7,0	
10, 12	70	7,0	
13	100	9,2	
14	70	9,2	

Table 7 Parameters used at testing of brake block C333 under snow conditions

Brake stop number	Speed [km/h]	Force [kN]	Comment
1, 3, 5, 7	100	6,3	Water flow 12 l/h
2, 4, 6, 8	70	6,3	Water flow 12 l/h
9, 11	100	7,5	Water flow 3 l/h
10, 12	70	7,5	Water flow 3 l/h
13	100	7,5	Water flow 3 l/h, conditioning from 120 km/h between stops
14	70	7,5	Water flow 3 l/h, conditioning from 120 km/h between stops

7 Data analyses

Preliminary braking distances were taken from the brake control system (not reported here). All other sampled braking data are taken from a DEWETRON stand-alone data acquisition system, imported and analysed using MATLAB software. In order to enhance general understanding of ice / snow effects at braking, a video camera was mounted inside the braking enclosure.

7.1 Braking distances

Results from brake bench testing is using two well-defined braking distances, see Figure 5:

- Distance "s_1", which is the distance between the instant when the brake application force starts to increase, to the instant when the wheel has stopped.
- Distance "s_2", which is the distance between the instant when the brake application force has reached its final constant value (defined as 95 % of the prescribed force), to the instant when the wheel has stopped.

The difference between these distances corresponds to the distance accumulated during the time of build-up of the pneumatic pressure. The build-up time, 3-4 s, is the same for all brake tests.

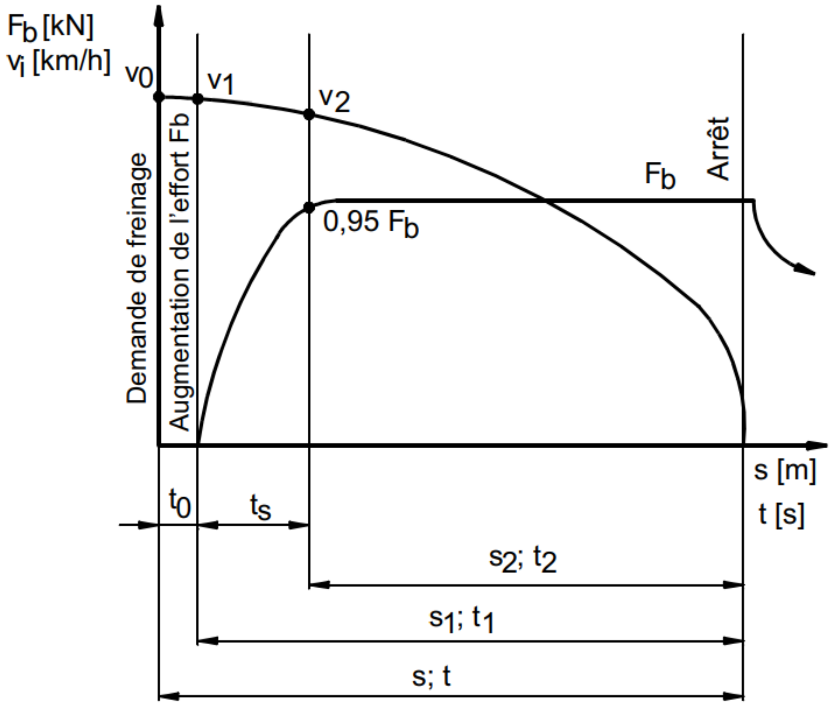


Figure 5 Definitions of braking distances "s_1" and "s_2", based on brake application force and speed, from UIC 541-4.

Note that the information from the brake control system was used at on-site assessment of braking performance in the form of stopping distances, whereas the data from the stand-alone system was used for monitoring all other data including measured temperatures in wheels and brake blocks. Since braking distances provided by the brake control system do not perfectly adhere to the UIC definitions it means that they somewhat deviated from those assessed using the stand-alone system. These differences are of little importance for the results in the present report. All results in this report are based on the standalone measurement system.

7.2 Block–wheel coefficient of friction and braking torque

For each stop, the measured mean coefficient of friction is calculated in accordance with UIC 541-4 [Ref. 4] meaning that the distance averaged value is calculated from the instantaneous friction coefficient μ_a as[8]:

$$\mu = \int_0^{s2} \mu_a \, ds$$

where the instantaneous coefficient of friction μ_a is calculated from knowledge of wheel radius R and from measured values of braking torque M_b and brake application force F_b as:

$$\mu_a = \frac{M_b/R}{F_b}.$$

In the results section, the time variation of the instantaneous coefficient of friction and also the braking torque histories are investigated, with special focus on the increase of braking torque, which regarding trend is mimicking the one of the instantaneous coefficient of friction.

8 Numerical investigation of temperatures on brake block friction surface and wheel tread

The temperatures in the friction surfaces of the brake blocks and the wheel tread are calculated over a sequence of conditioning brake cycles of a freight wheel at simulated line testing. The purpose is to identify the temperatures on the brake block surface and the wheel tread in order to understand, when and how an ice layer can develop on the brake block surface.

Based on
- the temperature measurements over a brake cycle, described in section 6.7,
- the thermal conductivity and thermal diffusivity for the brake block and the wheel
- the geometric of the brake block and the wheel, and
- the applied brake,

can the surface temperatures of the brake block and the wheel tread be calculated over a brake cycle.

The purpose is to identify
- how a thin ice layer can be developed on a brake block. As a baseline for further studies, it’s assumed that when the wheel tread has a temperature > 5 ºC and the block friction surface has a temperature < -5 ºC, then can snow that hits the wheel tread, melt and spray the friction surface of the block with water, where it freezes to a thin layer of ice,
- the difference between the two block that has been tested, and
- the influence of conditioning / exercising of the brake blocks in real operation.

It shall be noted that we expected to find material data for the brake blocks in ERADIS[9], but neither of the brake blocks had information regarding thermal conductivity and thermal diffusivity in any EC declaration of conformity of interoperability constituents [Ref. 6] [Ref. 7]

[8] Note that integration is performed over the distance s_2.
[9] https://eradis.era.europa.eu/

[Ref. 8]. Because of that was the thermal conductivity and thermal diffusivity measured at a laboratory [Ref. 10].

9 Results

Data acquired during tests are given in Appendix A for block J822 and in Appendix B for block C333. Time-variation of speed, brake application force, braking torque, temperatures of block, wheel, ventilation air inlet and outlet are shown. Based on these, the variation of coefficient of friction, braking power, energy, and retardation are also presented. In the following, the results for reference braking (cold conditions, without ice or snow) are presented, followed by results for ice conditions and for snow conditions.

Tabulated data extracted from test data are presented in Appendix C. An analysis of variation of coefficient of friction is given in Appendix D (detailed later in this chapter). For the sake of completeness have information on time of execution of each test in the brake bench been added to tables presented in Appendix E.

9.1 Reference braking

In the standard UIC 541-4 [Ref. 4], there are requirements on average friction during stops from different speeds and forces. Detailed requirements are given for 100 km/h that can readily be compared to the reference braking tests at the Becorit brake tests.

9.1.1 Block J822

It is for brake block type J822 found that the average friction resulting from tests at reference conditions are low, even lower than the minimum limit allowed for K blocks at 100 km/h in UIC 541-4 [Ref. 4]. The mean value for the six performed stops is about 0,26 and the nominal value according to the standard is 0,31. The brake block thus underperforms by some 14 % as compared to the nominal value of the standard. It can be noted that reference braking here was performed at the same low temperature as ice and snow braking, whereas values in the standard are for a testing at ambient temperature 20 ºC. Moreover, the allowed start temperature of performing a test according to the standard is 50 ºC.

Another reason for having a somewhat lower friction value at reference conditions could be that the contact width of the brake blocks on the wheel tread was about 70,5 mm. The width is somewhat less than the nominal 80 mm for the J822 block. Note that the EC declaration of conformity [Ref. 7] [Ref. 8] for the block states that the friction value for an un-bedded block is 0,22. The reason for the somewhat narrow contact is the large radius / chamfer on the block flange side, which infers that a contact width of 80 mm can result only after a (radial) wear on the block of some 10 mm. Additionally, the length is also reduced with approximately 15 mm due to transition radii on the front and back of the brake block.

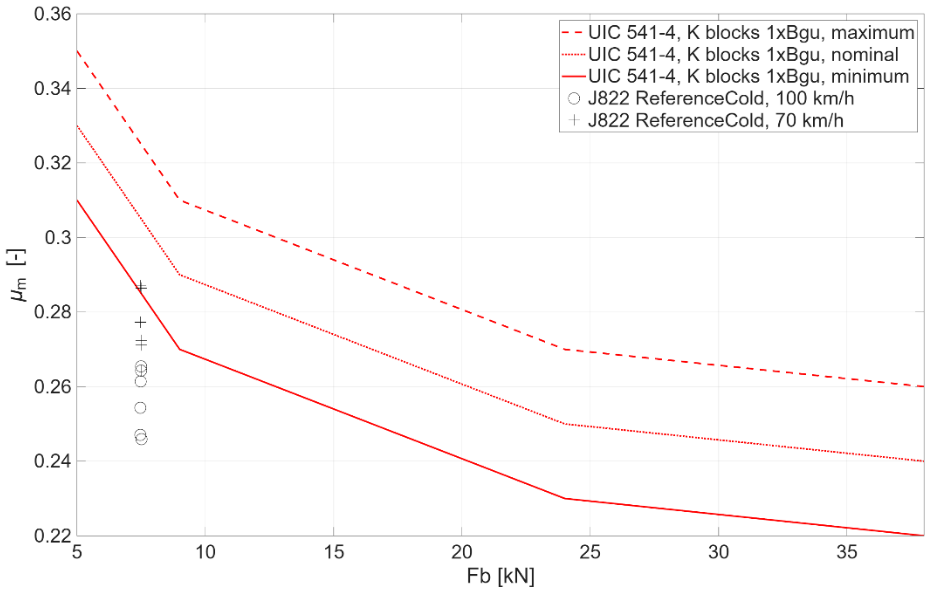


Figure 6 Calculated average coefficients of friction for testing of brake block J822 (1 x Bgu configuration) along with requirements according to UIC 541-4 at 100 km/h.

An overview of braking distances is presented in Table 8. The average s_1 braking distance is 541 m when braking from 100 km/h at application force 6,3 kN and 261 m from 70 km/h. The braking distance is thus approximately halved at the lower speed, which is in line with an assumed halving of the kinetic energy at the lower speed if one presumes a constant brake friction force.

Additional data have been extracted from the tests, see Appendix C. The quantities presented for each individual stop are braking distances s_1 and s_2, see Figure 5, and the related braking times of these distances t_1 and t_2 and also the time difference between them given as $\Delta t_{1\text{->}2}$. The latter is about 4 s for all tests. The remaining measures relate to time delays until onset of brake friction, and it here suffices to see that all are nil, no delays can be found, and a high coefficient of friction is established directly as the brake block is pushed towards the wheel.

Table 8 Overview of braking distances for brake block J822 at braking at reference conditions.

Cold and dry condition, reference distance					
Brake stop	Speed: 100 kph		Brake stop	Speed: 70 kph	
	Braking distance s1 [m]	Braking distance s2 [m]		Braking distance s1 [m]	Braking distance s2 [m]
1	514	411	2	264	196
3	562	456	4	267	198
5	546	446	6	261	192
7	559	460	8	254	185
9	533	427	10	254	185
11	534	435	12	263	194
Average	541,3	439,2	Average	260,5	191,7

9.1.2 Block C333

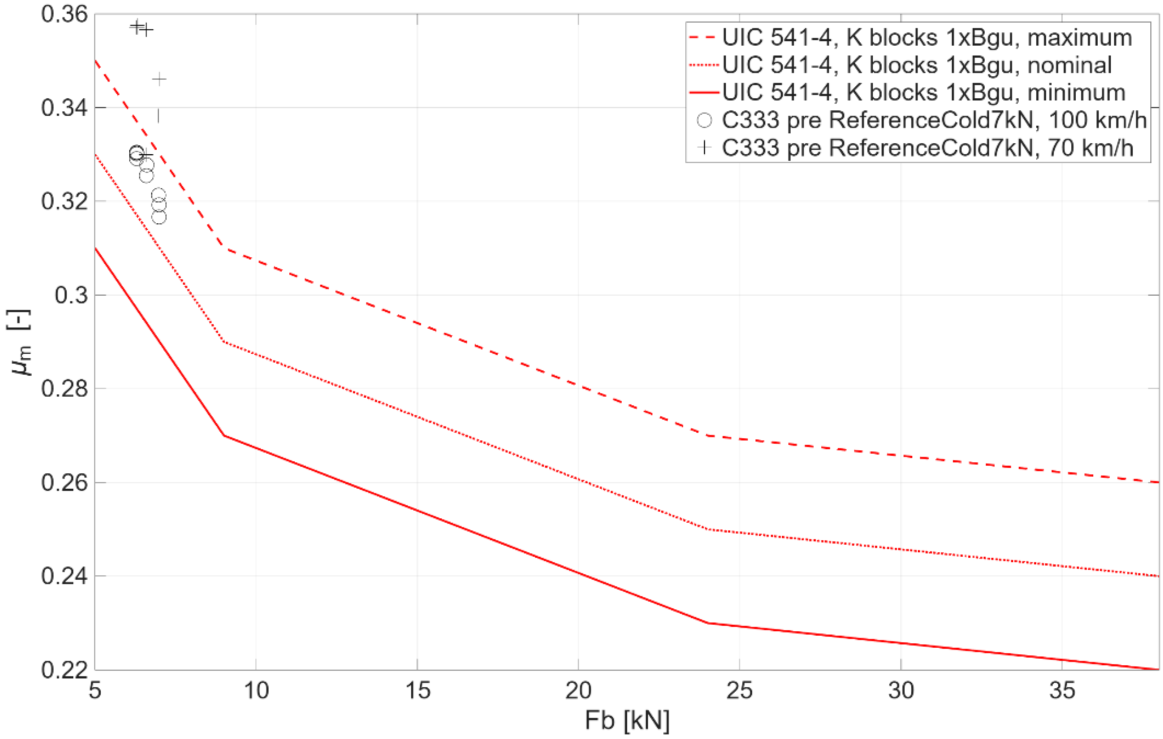
For brake block type C333 it is on the other hand found that the average friction resulting from tests at regular 6,3 kN reference conditions are somewhat high, and marginally higher than the maximum limit allowed for K blocks at 100 km/h in UIC 541-4 [Ref. 4], see Figure 7. The mean value for the six performed stops is about 0,34 and the nominal value according to the standard is 0,32. The brake block thus overperforms by some 8 % as compared to the nominal value of the standard. The braking distances are shown in Table 10.

At the early tests for finding a braking distance of block C333 as for the block J822, higher braking forces were tested, from 7 kN, down to 6,5 kN and 6,3 kN. Detailed results for these early stops can be found in Table 9. The friction values for these all fall inside the allowed range according to the standards UIC 541-4, see Figure 7. It can again be noted that reference braking here was performed at the same low temperature as ice and snow braking, whereas values in the standard are for a testing temperature of 20 ºC. As mentioned above, the start temperature of performing a test according to the standard is 50 ºC.

Table 9 Overview of braking distances of brake block C333 for three different force levels during search for reference conditions having similar braking distance as block J822.

Cold and dry condition 7kN, reference distance					
Brake stop	Speed: 100 kph		Brake stop	Speed: 70 kph	
	Braking distance s1	Braking distance s2		Braking distance s1	Braking distance s2
	[m]	[m]		[m]	[m]
1	485,4	376,6	2	237,1	164,6
3	479,3	362,7	4	239,9	164,6
Average	482,4	369,7	Average	238,5	164,6
Cold and dry condition 6.6kN, reference distance					
5	496,6	387,8	6	242,7	164,6
7	491	385	8	259,4	184,1
Average	493,8	386,4	Average	251,1	174,4
Cold and dry condition 6.3kN, reference distance					
9	510,5	404,5	10	251,1	175,8
11	510,5	401,7	12	251,1	175,8
Average	510,5	403,1	Average	251,1	175,8

Additional data have been extracted from the tests, see Appendix C. The quantities presented for the individual stops are braking distances s_1 and s_2, and the related braking times of these distances t_1 and t_2 and also the time difference between them given as $\Delta t_{1\text{->}2}$. The latter is about 4 s for all tests, as for block J822. As for block J822, the remaining measures that relate to time delays until onset of brake friction are all nil, meaning no delays can be found, and that a high coefficient of friction is established directly as the brake block is pushed towards the wheel.



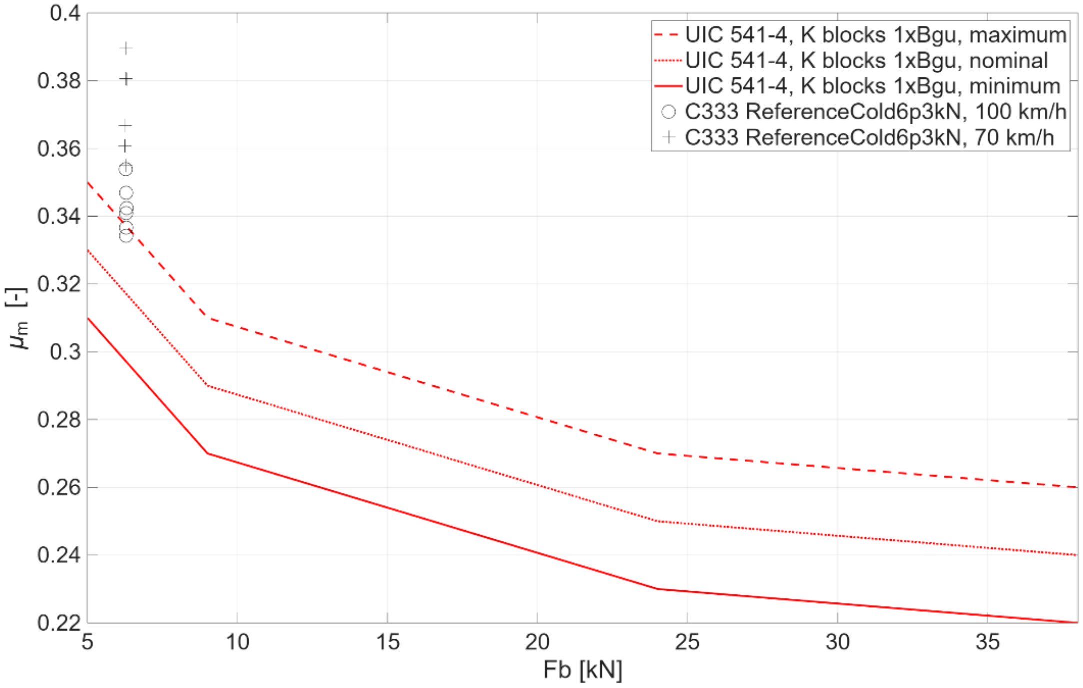


Figure 7 Calculated average coefficients of friction for testing of brake block C333 (1 x Bgu configuration) along with requirements according to UIC 541-4 at 100 km/h. Results for reference braking at three brake force magnitudes as part of pre-testing procedure (top) and regular reference braking at 6,3 kN (bottom).

Table 10 Overview of braking distances for brake block C333 at braking at reference conditions.

Cold and dry condition, reference distance with 6.3 kN					
Brake stop	Speed: 100 kph		Brake stop	Speed: 70 kph	
	Braking distance s1 [m]	Braking distance s2 [m]		Braking distance s1 [m]	Braking distance s2 [m]
1	482	389	2	223	155
3	466	367	4	236	172
5	476	378	6	229	161
7	487	388	8	235	166
9	477	385	10	229	161
11	485	393	12	242	173
Average	478,8	383,3	Average	232,3	164,7

9.2 Braking with ice on block contact surfaces

Results are presented for the two types of brake blocks, first for J822 and after that for C333.

9.2.1 Block J822

The registered braking speeds during brake block applications, i.e. corresponding to s_1, are shown in Figure 9 and an overview of braking distances are shown in Table 11. All measured data are presented in Appendix A and additional tabulated data can be found in Appendix C.

The variations of speed as a function of braking distance (s_1), see Figure 9, show that ice on the brake blocks increases the braking distance substantially, both when braking from 100 km/h and 70 km/h. The braking performance is very poor, with the average braking distance being almost doubled when braking from 100 km/h and quadrupled when braking from 70 km/h. Braking from 70 km/h results in similar braking distances as when braking from 100 km/h. The braking distance can be seen to be shortened substantially at the one test using a higher force from 100 km/h as compared to when braking with the regular force (9,24 kN application force vs 7,5 kN). Note that no reference brake stops at dry conditions were made for the higher application force.

Based on measured data and videos captured during braking, it was found that a typical sequence of events during braking was

1) Brake force is applied during 4 s and friction is very low.
2) The ice layer on the brake blocks slowly melts and can be observed to at least partially transfer to the cold wheel tread where a thin white layer develops. The coefficient of friction stays low.
3) Suddenly, the ice starts to break up under a cascade of ice being spread in the test chamber, emanating from the front edge of the brake block. The scattered ice/snow seems to come from the ice that had transferred to the wheel tread.
4) Friction slowly increases towards higher values leading to more substantial speed reduction. In addition, the ice in the notch at mid-length of the brake blocks melts and steam can be seen to evaporate.

It was during testing noted that the braking distances tended to increase for every new brake test. When depositing the ice layer on the friction surfaces of the brake blocks for making the next winter stop braking test, it was observed that the friction surface was partially still covered with thin layers of ice, see Figure 8. This is an indication that the programmed stop braking directly after a winter test, braking from 50 km/h, could not reset the conditions of the blocks – wheel system to an initial state. It can be noted that a more powerful condition braking from 120 km/h is performed in-between winter tests according to UIC 541-4 [Ref. 4].

Figure 8. Brake blocks with remaining ice on friction surface. After brake cycle no 6, with 7,5 kN, and after conditioning brake from 50 km/h. Picture is taken directly after the brake blocks are removed from test bench.

Moreover, at continued testing, the notch at mid-length of the brake block could be observed to fill-up with ice/snow that forced the width of the notch to increase. An effort was made to measure this by a caliper[10] and it was found that the width of the notch towards the wheel increased by 0,5 mm for one block and 1 mm for the other brake block. This could tentatively point towards a change of block geometry by straightening each block, which could lead to less contact between brake block forward edge and wheel tread. This could have negative effects on the ice-breaking performance of the blocks, see item 3 on previous page.

A complete deicing of the brake blocks was made after brake stop no 6, see Table 11. It was found that this had a positive effect on the braking distances, breaking the trend of increasing distances, but the braking distance were still larger than for the initial stops.

[10] Measured with the brake blocks on a work bench. Obviously without application force.

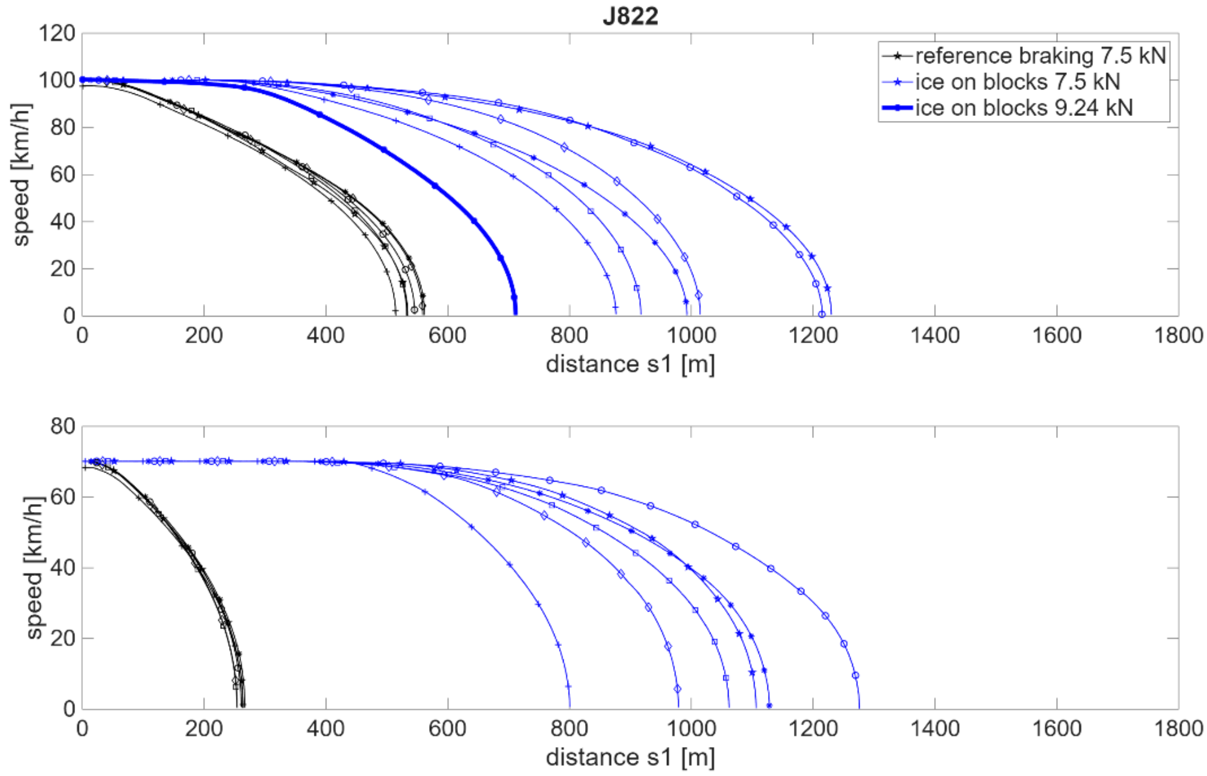


Figure 9 Braking distances for situation with ice on brake block contact surface at braking forces 7,5 kN (thin blue lines) and 9,24 kN (thick blue line), along with results for reference braking at 7,5 kN (thin black lines). Top diagram is braking from 100 km/h, bottom is from 70 km/h.

Table 11 Overview of braking distances for brake block J822 at braking at ice conditions.

Ice condition 7.5 kN					
Brake stop	Speed: 100 kph		Brake stop	Speed: 70 kph	
	Braking distance s1	Braking distance s2		Braking distance s1	Braking distance s2
	[m]	[m]		[m]	[m]
1	876	769	2	800	730
3	993	892	4	1128	1057
5	1215	1114	6	1276	1205
Deicing of brake shoes with heat gun, cleaning of notch in shoes					
7	1015	914	8	979	903
9	917	816	10	1062	991
11	1230	1122	12	1106	1031
Ice condition, braking force 9240 N					
1	712	691	na	na	na
Average7.5kN	1041,0	937,8	Average	1058,5	986,2
Average9.2kN	712,0	691,0		na	na

Detailed results are given in Appendix A, first in a figure showing variations of measured data for each stop and secondly variations of calculated results in a second figure. For the measured data, which shows the variation from 10 s prior to brake application until complete stop, it can be seen that:

1) The build-up of braking torque does not follow the braking force. It is low at initiation of braking and remains low until it starts to increase after some time.
2) The wheel temperatures as measured by thermocouples T2 and T3 below tread can be seen to increase during braking. There is a slight increase in thermecouple T1 indicating that the heat input near this thermocouple position (towards the wheel flange) is minor. This is similar to behaviour at reference braking.
3) The brake block temperatures as measured at mid block thickness and at 10 mm below contact surface are found to have minor changes or none. This is again similar to the behaviour at reference braking.
4) The measured temperatures of air inlet and outlet to the braking enclosure are not affected by braking. Some variations in the inlet temperature can be found in the form of *lowering* of this temperature, which is an effect of the automatic operation of the brake bench cooling system.

For the calculated data, which shows the variation from the time point when the brake pressure has reached 95% of its maximum value, corresponding to distance s_2, until complete stop, it can be seen that:

1) The coefficient of friction increases from a very low initial value of about 0,01.
2) The coefficient of friction increases during a major part of the duration of braking, but can reach a constant value towards end of braking. The maximum friction towards the end is generally lower than the highest one found at the end of braking under reference conditions.
3) The increase in friction is generally montonic and steady.
4) The power variations show a delayed peak, caused by the delayed onset of friction combined with the decrease of speed. The accumulated work is however about 1000 kJ after all stop from 100 km/h and 500 kJ after 70 km/h, as expected.

5) Retardation during braking can reach as high values as the ones at reference conditions at 100 km/h, but never at 70 km/h when retardation always is substantially lower than at reference conditions.

An effort was made to quantify some measures that tentatively could help explaining the poor braking performance at ice conditions. Tables for all stops are provided in Appendix C and an example is given in Table 12 for ice braking from 100 km/h at force 7,5 kN. Tabulated are the previously mentioned braking distances s_1 and s_2 (and their corresponding durations t_1 and t_2), supplemented with:

- Δs_μ and Δt_μ are distance and time respectively, from start of s_2 (when the brake normal force has reached a high value) until the braking friction has reached 75% of the average coefficient of friction for the studied stop.
- Δs_{acc} and Δt_{acc} are distance and time respectively, from start of s_2 until the braking retardation has reached 50% of the maximum retardation of the studied stop.
- Δs_{acc}^{REF} and Δt_{acc}^{REF} are distance and time respectively, from start of s_2 until the braking retardation has reached 75% of the average retardation during reference stops.

From Table 12 some observations can be made (ice, 7,5 kN, 100 km/h):

1) The distance Δs_μ until the brake friction reaches 75% of the average friction value for the individual stop is on an average somewhat shorter than half of braking distance s_2, and that they have similar standard deviations.
2) The distance Δs_{acc} until 50% of the maximum retardation for the individual stop is reached, is on an average somewhat larger than half the braking distance s_2 and it has a larger standard deviation than s_2.
3) The distance Δs_{acc}^{REF} until 75% of the retardation at reference tests is reached, is on an average reached at about two thirds of the braking distance s_2.

By comparison of the average values from braking at 7,5 kN in Table 12 with the braking case having a higher brake normal force of 9,24 kN, see Table 6 in Appendix C, it is found that the braking distance s_2 is shortened by 24 % for the higher force and that the distances Δs_μ and Δs_{acc} are reduced by 35 and 40 % respectively.

Braking from 70 km/h with 7,5 kN, see table 7 in Appendix C, has a braking distance that is somewhat *longer* than when braking from 100 km/h at the same force:

1) The distance Δs_μ until the brake friction reaches 75% of the average friction value for the individual stop is on an average somewhat longer than half of braking distance s_2, and that they have similar standard deviations.
2) The distance Δs_{acc} until 50% of the maximum retardation for the individual stop is reached, is on an average reached after 76 % of braking distance s_2.
3) The distance Δs_{acc}^{REF} until 75% of the retardation at reference tests is reached, is never reached during the stop.

In total, all the quantities point towards poor braking performance of the brake block J822 when tested at conditions with ice on the brake block friction surface.

Table 12 Results for brake block J822 at braking at ice conditions 100 km/h, 7,5 kN. Average value and standard deviation of column data are given in two last rows. The column on right contains comments: (A) Brake blocks and wheel were completely de-iced after run 6 and were clean upon initiation of winter preparations before run 7.

run	s_1 [m]	t_1 [s]	s_2 [m]	t_2 [s]	$\Delta t_{1\text{->}2}$ [s]	Δs_μ [m]	Δt_μ [s]	Δs_{acc} [m]	Δt_{acc} [s]	Δs_{acc}^{REF} [m]	Δt_{acc}^{REF} [s]	
1	876	49	769	45	3,9	259	9	246	9	418	16	
3	993	56	892	52	3,6	336	12	324	12	553	22	
5	1215	64	1114	60	3,6	589	22	654	24	764	29	
7	1015	52	914	49	3,6	486	18	551	21	591	22	(A)
9	917	49	816	45	3,6	381	14	399	15	452	17	
11	1230	64	1122	60	3,9	591	22	717	27	830	33	
avg	1041	56	938	52	3,7	440	16	482	18	602	23	
std	149	7	149	7	0,1	137	5	188	7	166	7	

9.2.2 Block C333

The registered braking speeds during brake block applications, i.e. corresponding to distance s_1, are shown in Figure 10 and an overview of braking distances are shown in Table 13. All measured data are presented in Appendix B and additional tabulated data can be found in Appendix C.

The variations of speed as a function of braking distance (s_1), see Figure 10, show that ice on the brake blocks increases the braking distance substantially, both when braking from 100 km/h and 70 km/h, similar to the behaviour of brake block J822. The braking performance is very poor, with the average braking distance being more than doubled when braking from 100 km/h (similar to J822) and 9-12 times longer when braking from 70 km/h (it was 4 times longer for J822). Braking from 70 km/h results in much longer braking distances as compared to braking from 100 km/h.

The braking distances can be seen to be shortened when the brake force is increased. However, comparison to pre-testing reference braking at 7 kN and 100 km/h shows that the s_2 braking distance has approximately doubled also for this higher force. The ratio of stopping distance to reference conditions is here 2,0 which is somewhat lower than 2,4 for 6,3 kN. When braking with the highest force 9,24 kN, the braking distances are again shortened, but no reference braking stops were performed, as for J822, at this higher force magnitude.

Braking from 70 km/h results in substantially longer braking distances than braking from 100 km/h (they were about the same for J822). The braking distance can be seen to be shortened as the braking force increases, but in order to reach a braking distance similar to the one at 6,3 kN at 100 km/h a force 9,24 kN seems to be required.

A typical sequence of events during braking is rather similar to the one of block J822, however with a difference after the ice layer breaks (item 4 below):

1) Brake force is applied during 4 s and friction is very low.
2) The ice layer on the brake blocks slowly melts and can be observed to at least partially transfer to the cold wheel tread where a thin white layer develops. The coefficient of friction stays low.
3) Suddenly, the ice starts to break up under a cascade of ice being spread in the test chamber, emanating from the front edge of the brake block. The scattered ice/snow seems to come from the ice that had transferred to the wheel tread.[11]
4) Friction for block C333 increases *rapidly* towards higher values leading to more substantial speed reduction, which can be compared to a slow increase in friction for block J822.

Whereas substantial history effects (from previous brake applications) could be found for block J822 that indicatively caused braking distances becoming longer by every stop, no such effect was found for brake block C333. Moreover, since the sintered brake block C333 does not have a notch at mid-length of the brake block, there could be no snow accumulation there. No deicing of the brake blocks was performed during the ice tests of block C333.

From the detailed analyses given in Table 14 some observations can be made (ice, 6,3 kN, 100 km/h):

1) The distance Δs_{μ} until the brake friction reaches 75 % of the average friction value for the individual stop is on an average about half of braking distance s_2. This is similar to J822.
2) The distance Δs_{acc} until 50% of the maximum retardation for the individual stop is reached, is on an average about half the braking distance s_2. This is similar to J822.
3) The distance Δs_{acc}^{REF} until 75 % of the retardation at reference tests is reached, is on an average reached at about two thirds of the braking distance s_2. This is similar to J822.

Comparison the average values from braking at 6,3 kN in Table 14 with the braking case having a higher brake normal force 9,24 kN, see Table 13 in Appendix C, it is found that the braking distance s_2 is shortened by 31 %, (24 % for J822) when increasing the force and that the distances Δs_{μ} and Δs_{acc} are reduced by about 50 % (35 and 40 % respectively for J822).

Braking from 70 km/h with 6,3 kN, see table 7 in Appendix C, has a braking distance that is substantially *longer* than when braking from 100 km/h at the same force.

1) The distance Δs_{μ} until the brake friction reaches 75 % of the average friction value for the individual stop, is on an average somewhat longer than half of braking distance s_2. This is similar to J822.
2) The distance Δs_{acc} until 50% of the maximum retardation for the individual stop is reached, is on an average reached after 81 % of braking distance s_2 (J822 had 76 %)
3) The distance Δs_{acc}^{REF}until 75 % of the retardation at reference tests is reached, is never reached during the stop. This is the same outcome as for J822.

[11] Note that observations were only possible for the upper part of the brake blocks including top front end.

In total, all the quantities point towards poor braking performance of the brake block C333 when tested at conditions with ice on the brake block friction surface.

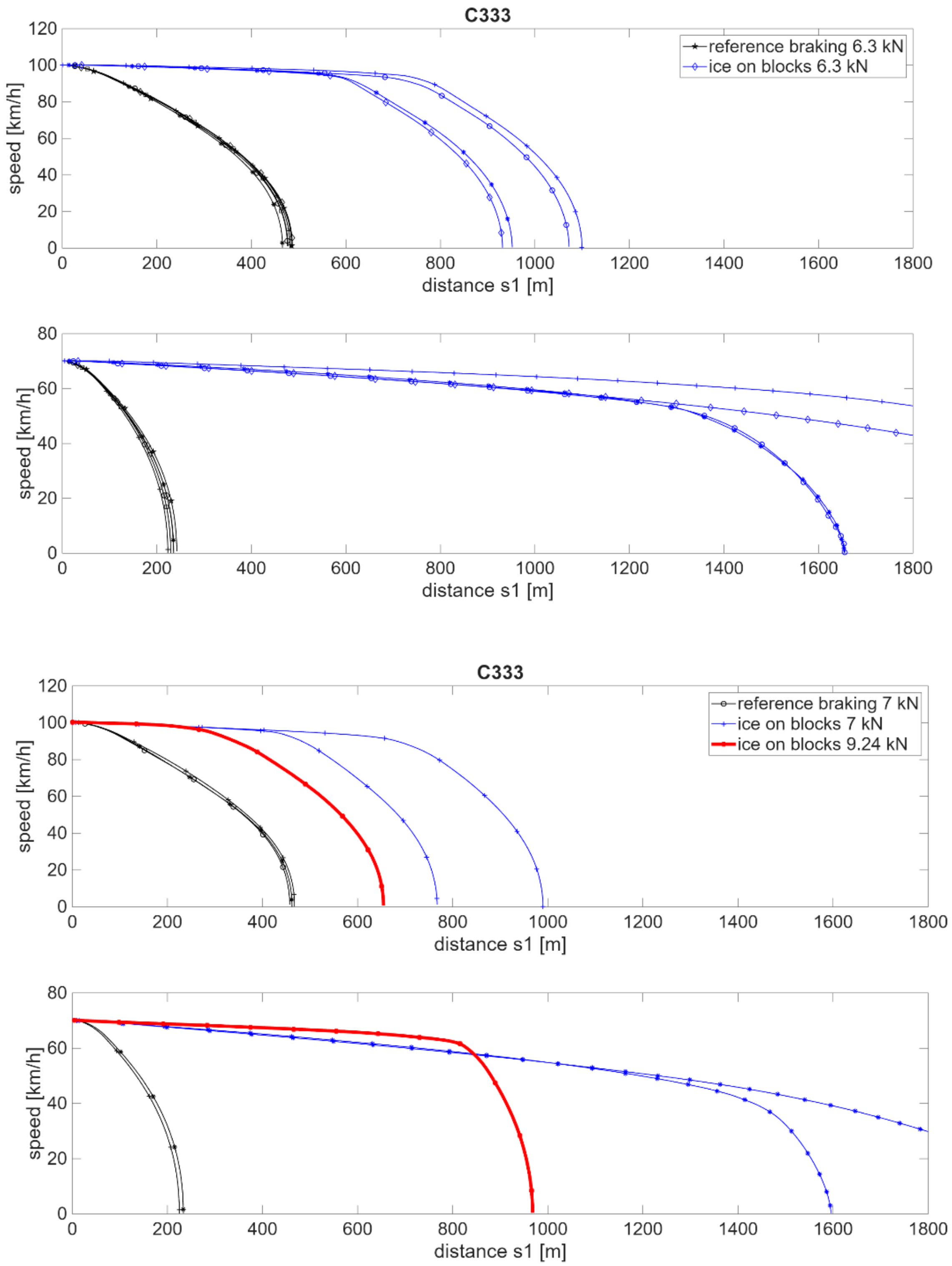


Figure 10 Braking distances for situation with ice on brake block contact surface at braking forces 6,3 kN in top two graphs and in bottom two graphs at 7 kN and 9,24 kN.

Table 13 Overview of braking distances for brake block C333 at ice conditions. Note that there was air leakage in the snow cannon air flow for test runs 1 and 2, which resulted in ice build-up on wheel treads during cooling periods. They are not considered for calculation of average values.

Ice condition, 6.3 kN					
Brake stop	Speed: 100 kph		Brake stop	Speed: 70 kph	
	Braking distance s1	Braking distance s2		Braking distance s1	Braking distance s2
	[m]	[m]		[m]	[m]
1	1100	1005	2	2134	2063
3	952	851	4	1654	1584
5	1072	971	6	1656	1585
7	931	824	8	2640	2565
Ice condition, 7 kN					
9	767	660	10	1595	1525
11	990	890	12	2140	2070
Ice condition, braking force 9240 N, manual mode					
1	654	634	2	968	954
Average6.3kN	985,2	882,2	Average	1983,3	1911,3
Average6.6kN	878,5	775,0	Average	1867,5	1615,1
Average9.2kN	654,0	634,0	Average	968,0	954,0

Table 14 Results for brake block C333 at braking at ice conditions 100 km/h, 6,3 kN. Average value and standard deviation of column data are given in two last rows.

run	s_1 [m]	t_1 [s]	s_2 [m]	t_2 [s]	$\Delta t_{1\text{->}2}$ [s]	Δs_μ [m]	Δt_μ [s]	Δs_{acc} [m]	Δt_{acc} [s]	Δs_{acc}^{REF} [m]	Δt_{acc}^{REF} [s]
1	1100	53	1005	50	3,4	638	23	669	25	682	25
3	952	48	851	45	3,6	492	18	498	18	523	19
5	1072	53	971	49	3,6	619	23	638	24	662	25
7	931	47	824	43	3,9	484	18	484	18	509	19
avg	1014	50	913	47	3,6	558	21	572	21	594	22
std	84	3	89	3	0,2	82	3	95	4	91	3

9.3 Braking with snow on block contact surfaces and on wheel tread

Results are presented for the two types of brake blocks are presented below. It can be observed that the requirement for approval in UIC 541-4 is that the permitted deviation of the average value of braking distance s_1 over a test programme (100 km/h) is ± 15 % as compared to reference conditions.

9.3.1 Block J822

The registered braking speeds during brake block applications, i.e. corresponding to s_1, are shown in Figure 11 and an overview of braking distances are shown in Table 15. All measured data are presented in Appendix A and additional tabulated data can be found in Appendix C.

The variations of speed as a function of braking distance (s_1), see Figure 11, show that snow on the brake blocks and on the wheel tread increases the braking distance substantially both when braking from 100 km/h and 70 km/h. When comparing to braking with ice on the blocks, a larger spread in braking distances can be found. Braking from 70 km/h results in similar braking distances as when braking from 100 km/h. It can be noted that history effects observed at braking with ice on blocks are present also here, in that the shortest braking distances are found after the brake blocks have been de-iced prior to a test (the three shortest at 100 km/h and the shortest at 70 km/h). The three tests at 100 km/h for which the brake blocks have previously been de-iced have an average braking distance 720 m and the others have 1210 m. It can be noted that the reference average braking distance is 541 m and thus that 720 m indicates a prolongation of the braking distance by 34 %.

Based on measured data and videos captured during braking, it was found that a typical sequence of events during when braking 100 km/h was:

1) Brake force is applied during 4 s and snow from the wheel tread spread in the test chamber immediately on block contact with wheel, with some snow trapped between brake blocks and wheel. The friction is between 0,05 and 0,1 when the blocks are initially ice free and hence a significant amount of heat is generated. The friction and the heating are distinctly less if the blocks are not ice free prior to tests.
2) The snow layer that has formed between block and wheel slowly melts under the generated heat if the brake blocks were priorly ice free and the coefficient of friction then increases. Melting snow can be seen to be trapped in front of the upper brake block, accumulating in the block upper face. If the brake blocks were not initially ice/snow free it takes a longer time until the coefficient of friction increases and the snow starts to melt on the brake blocks.
3) After the melting of the snow layer, friction increases towards higher values leading to more substantial speed reduction.

Braking from 70 km/h result in very weak melting on blocks and the friction seldomly increases during a stop, indicating that the trapped ice/snow remains during at least a major part of the braking event.

In summary, there is a quantifiable difference between tests for which the brake blocks have been completely deiced and the tests that have previously been tested without deicing. Again, it can be noted that the tests, here performed, have a 50 km/h stop directly after a winter brake tests, while at UIC 541-4 [Ref. 4] testing it is a 120 km/h stop that is employed. The latter would presumably provide a substantial deicing of blocks and wheel thanks to the high energy that is transformed into heat.

During snow testing, also the water flow to generate snow was varied. At the first four brake stops (two at 100 and two at 70 km/h) the water flow was 12 l/h, which according to Becorit staff corresponded to a setting typically used for UIC 541-4 tests, and for the next four stops it was reduced to 6 l/h and it was again reduced to 3 l/h for the last four stops. No clear tendencies in braking distances could be observed, possibly because of the previously described history effects that are present during the entire test sequence.

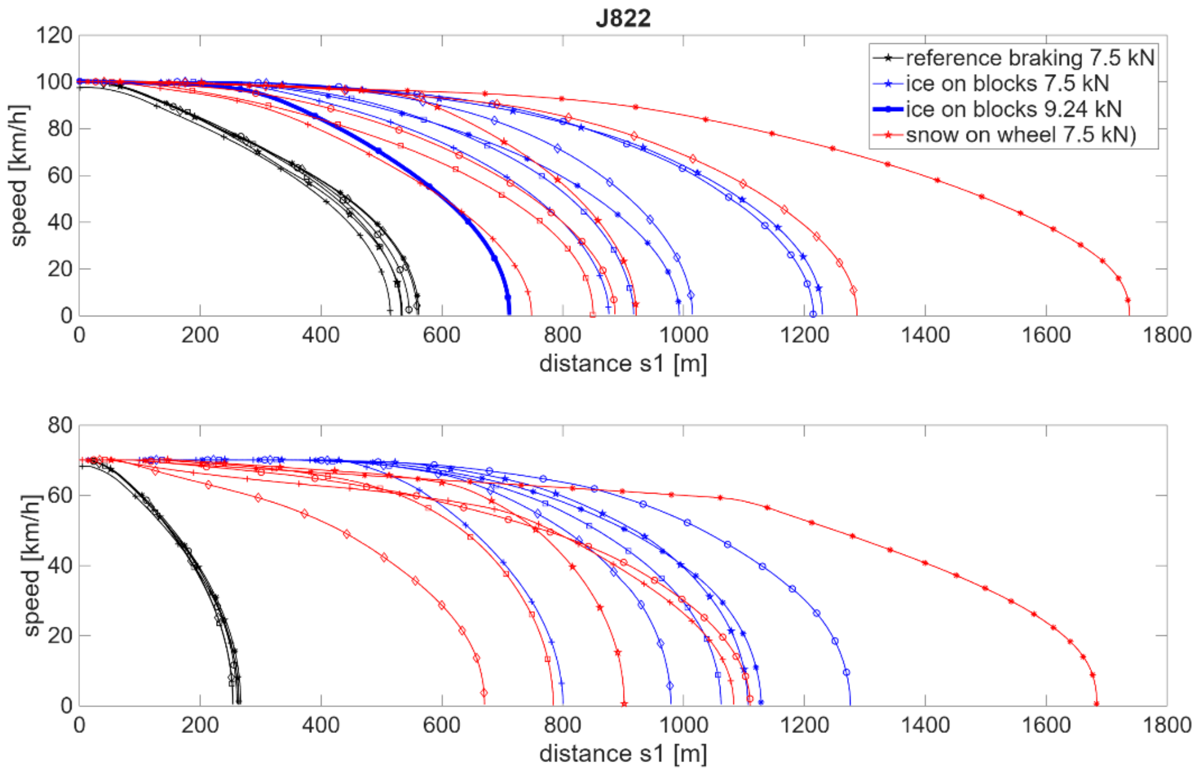


Figure 11 Braking distances for situation with snow on brake block contact surface at braking forces 7,5 kN, along with results for ice on brake blocks at 7,5 kN and 9,24 kN.

Table 15 Overview of braking distances for brake block J822 at braking at snow conditions. Note that blocks and wheel were free from ice prior to test 1, 5, 8 and test 9.

Snow condition					
Brake stop	Speed: 100 kph		Brake stop	Speed: 70 kph	
	Braking distance s1 [m]	Braking distance s2 [m]		Braking distance s1 [m]	Braking distance s2 [m]
Water flow to generate snow: 12 l/h					
1	748	641	2	1083	1012
3	1738	1630	4	1684	1613
Shoes deiced and dryed after 4; water flow to generate snow: 6 l/h					
5	886	779	6	1110	1034
7	1287	1186	8	670	600
Shoes deiced and dryed after 8; water flow to generate snow 3 l/h					
9	850	749	10	784	709
11	922	821	12	902	831
Average	1071,8	967,7	Average	1038,8	966,5

From the detailed information in Table 16 some observations can be made (snow, 7,5 kN, 100 km/h):

1) The distance Δs_{μ} until the brake friction reaches 75% of the average friction value for the individual stop show remarkable differences between stops that are performed

directly after deicing of blocks and the other tests. Tests performed directly after deicing have an average of 220 m and the others have 620 m.

2) The distance Δs_{acc} until 50 % of the maximum retardation for the individual stop is reached, show similarly large difference between tests directly after deicing with an average of 240 m and the others have 950 m.

3) The distance Δs_{acc}^{REF} until 75% of the retardation at reference tests is reached, again show similarly large difference between tests directly after deicing with an average of 370 m and the others have 990 m.

Braking from 70 km/h with 7,5 kN, which has a braking distance that is on average about the same as when braking from 100 km/h, has detailed information in Table 15 in Appendix C,

1) The distance Δs_{μ} until the brake friction reaches 75% of the average friction value for the individual stop is longer than the one for J822 snow at 100 km/h. No large difference can be found for stop 8, which has deicing directly prior to test, and the others.

2) The distance Δs_{acc} until 50% of the maximum retardation for the individual stop is reached, is on an average reached after 82% of braking distance s_2.

3) The distance Δs_{acc}^{REF} until 75% of the retardation at reference tests is reached, is reached at the very end (at about 90% of the braking distance) of the two last tests, but not for the four earlier stops.

In total, all the quantities point towards poor braking performance of the brake block J822 when tested at conditions with snow on wheel and on the brake block friction surface.

Table 16 Results for brake block J822 at braking at snow conditions 100 km/h, 7,5 kN. Average value and standard deviation of column data are given in two last rows.

run	s_1 [m]	t_1 [s]	s_2 [m]	t_2 [s]	$\Delta t_{1->2}$ [s]	Δs_{μ} [m]	Δt_{μ} [s]	Δs_{acc} [m]	Δt_{acc} [s]	Δs_{acc}^{REF} [m]	Δt_{acc}^{REF} [s]	
1	748	47	641	44	3,9	172	7	154	6	214	8	
3	1738	95	1630	91	3,9	782	29	1601	82	1630	90	
5	886	52	779	48	3,9	272	10	266	10	427	17	
7	1287	68	1186	64	3,6	644	24	775	30	858	34	
9	850	50	749	47	3,6	217	8	304	12	469	20	
11	922	47	821	44	3,6	442	16	467	17	479	18	
avg	1072	60	968	56	3,8	422	16	595	26	679	31	
td	374	19	374	19	0,1	248	9	538	28	510	30	

9.3.2 Block C333

The registered braking speeds during brake block applications, i.e. corresponding to s_1, are shown in Figure 12 and in Figure 13, and an overview of braking distances are shown in Table 17. All measured data are presented in Appendix B and additional tabulated data can be found in Appendix C.

The variations of speed, when braking with 6,3 kN force from 100 km/h, as a function of braking distance (s_1) is shown in Figure 13. For the first two stops with snow, on brake blocks and on wheel tread, have short braking distances with a small increase of merely 9 % as compared to reference conditions. After this, a possible history effect can be observed, and the braking distances increase substantially for the last two stops. Braking from 70 km/h results in extremely long braking distances for all four stops.

For block C333, snow tests were performed also for the higher brake force 7,5 kN (same as used on block J822), see Figure 13, and for this higher force, the braking distance was somewhat reduced as compared to braking at 6,3 kN. It should be noted that according to videos have the brake blocks been deiced prior to test no 9 at this higher force. Since no reference brake tests were performed at 7,5 kN, the values from pre-testing at 6,3 kN, 6,6 kN and 7,0 kN were used to extrapolate reference braking results. Comparison then indicatively shows that the snow testing gives a prolongation of 13 % as compared to reference when braking from 100 km/h. Brake distances when braking from 70 km/h are still very long when braking at this force, but they are shorter than at 6,3 kN.

Another variation was performed for block C333, in that conditioning braking at 120 km/h was introduced in-between stops for the last four tests at 7,5 kN, thus similar to UIC 541-4 [Ref. 4] testing, instead of 50 km/h used for the other tests. It is found when braking from 100 km/h that the braking distances for these tests have an average prolongation of 5 % when compared to the extrapolated reference distance. The braking distances when braking from 70 km/h are vastly shortened, going from average 1614 m in average to 430 m when using the powerful condition braking. It is still however about twice the braking distance of reference conditions. The powerful condition braking evidently has a significant impact on the braking distances of the following snow braking.

Based on measured data and videos captured during braking, it was found that a typical sequence of events during braking from 100 km/h was:

1) Brake force is applied during 4 s and snow from the wheel tread spread in the test chamber immediately on block contact with wheel, with some trapped between brake blocks and wheel. The friction is between 0,05 and 0,1 when the blocks are initially ice free and hence a significant amount of heat is generated. The friction and the heating are distinctly less if the blocks are not ice free prior to tests.
2) The snow layer that has formed between block and wheel slowly melts under the generated heat if the brake blocks were priorly ice free and the coefficient of friction then increases. Melting snow can be seen to be trapped in front of the upper brake block, accumulating on the block upper face. If the brake blocks were not initially ice/snow free it takes a longer time until the coefficient of friction increases and the snow starts to melt on the brake blocks.
3) After melting of the snow layer, friction increases towards higher values leading to more substantial speed reduction.

Similar to braking with block J822, braking from 70 km/h result in very weak melting on blocks. Trapped ice/snow remains during at least a major part of the braking event.

From the detailed analyses given in Table 18 some observations can be made (snow, 6,3 kN, 100 km/h):

1) The distance Δs_{μ} until the brake friction reaches 75% of the average friction value for the individual stop is very short for the first two stops (120 m and 72 m), that show short braking distances. The corresponding time delay is below 5 s.
2) The distance Δs_{acc} until 50% of the maximum retardation for the individual stop is reached, shows the same trend as above (item 1).
3) Also, the distance Δs_{μ} until 75 % of the retardation at reference tests is reached, shows the same trend as above.

Braking from 100 km/h at force 7,5 kN, see Table 18 in Appendix C, gives similar short values as the initial two stop tests when braking with 6,3 kN. Braking at 7,5 kN with enhanced conditioning from 120 km/h, see Table 20 in Appendix C, shows even shorter delays, (46 m and 26 m; 2 s and 1 s).

Braking from 70 km/h with 6,3 kN and 7,5 kN see tables 17 and 19 in Appendix C, generally show that neither of the quantities discussed above are reached during stops. However, when using the more powerful 120 km/h condition braking cycles, they are reached, but only after half the braking distance has passed.

In total, all the quantities point towards reasonable to good braking performance of the brake block C333 when tested from 100 km/h at conditions with snow on wheel and on brake block friction surface. Braking performance from 70 km/h is poor.

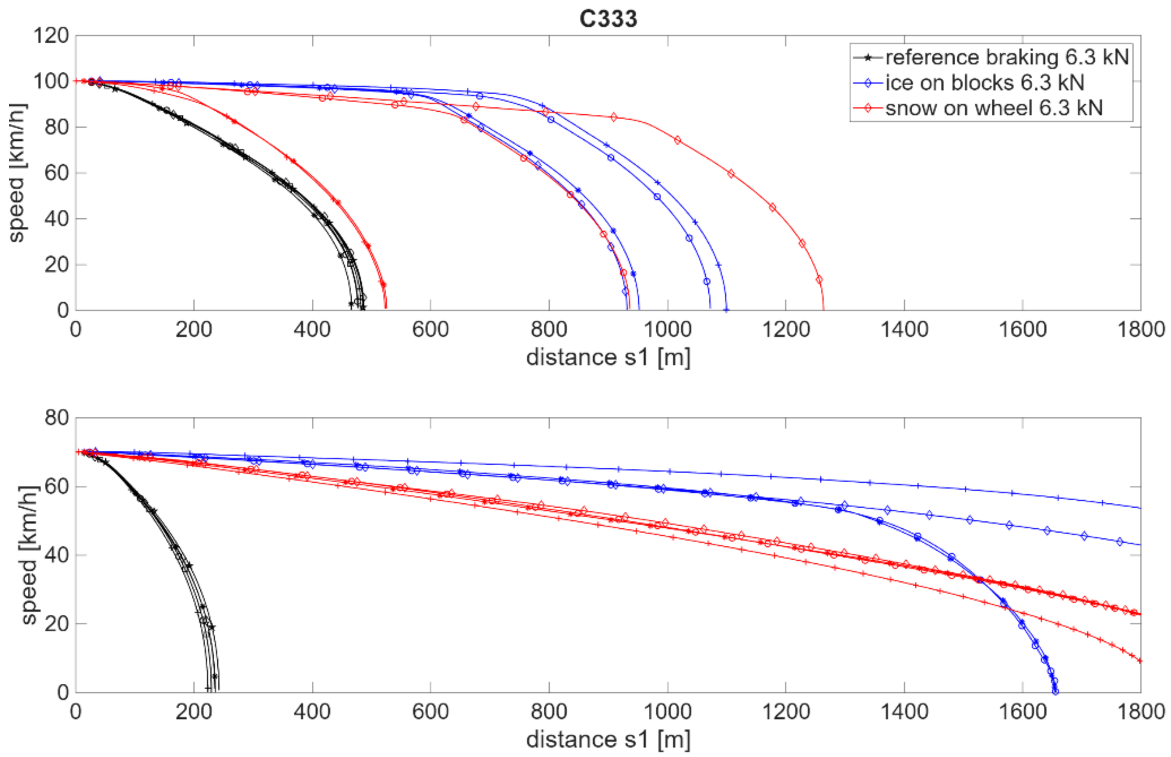


Figure 12 Braking distances for situation with ice on brake block contact surface at braking forces 6,3 kN.

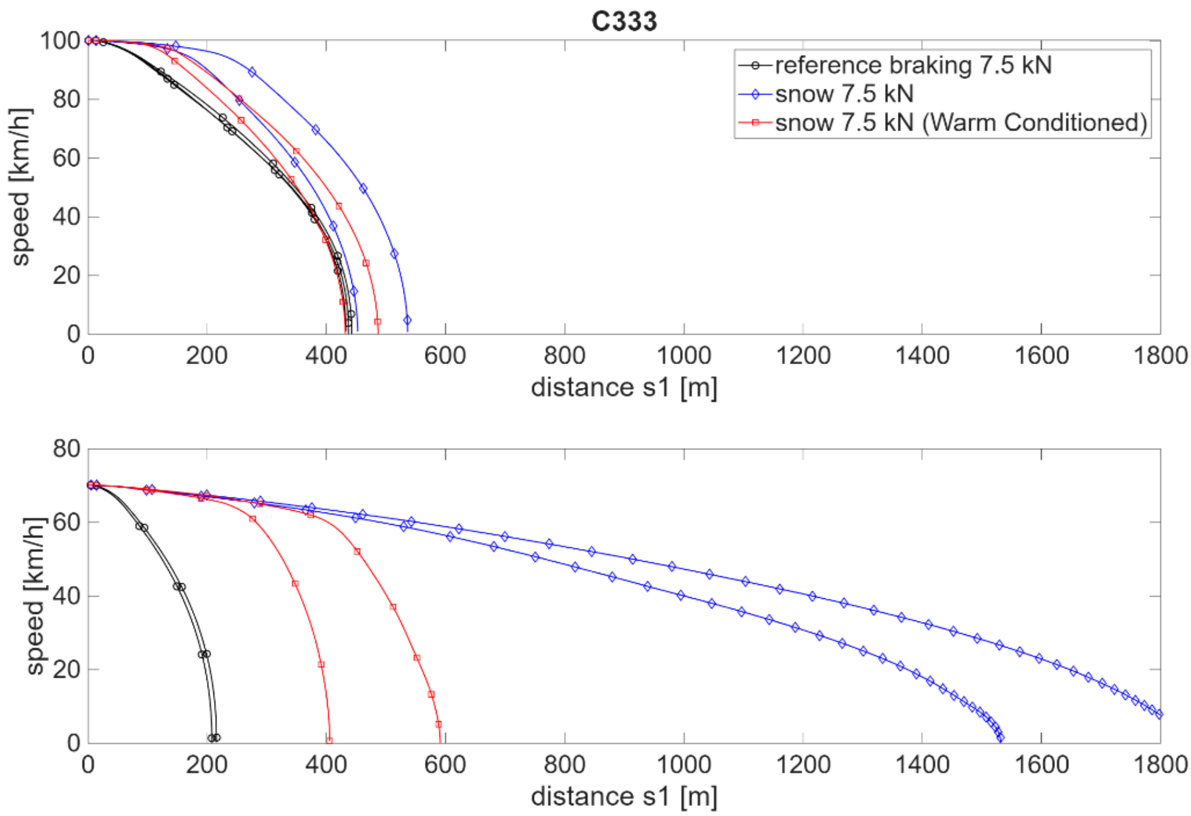


Figure 13 Braking distances for situation with ice on brake block contact surface at braking forces 7,5 kN, along with results for ice on brake blocks at 7,5 kN and 9,24 kN. Note that the results for reference braking at 7,5 kN have been extrapolated from pre-test results.

Table 17. Overview of braking distances for brake block C333 at braking at ice condition.

Snow condition, 6.3 kN					
Brake stop	Speed: 100 kph		Brake stop	Speed: 70 kph	
	Braking distance s1 [m]	Braking distance s2 [m]		Braking distance s1 [m]	Braking distance s2 [m]
Water flow to generate snow: 12 l/h					
1	523	429	2	1837	1772
3	525	418	4	2049	1979
5	936	836	6	2102	2032
7	1264	1163	8	2108	2038
Snow condition, 7.5 kN, Water flow to generate snow: 3 l/h					
9	453	359	10	1532	1466
11	536	443	12	1832	1762
Snow condition, 7.5 kN, Water flow to generate snow: 3 l/h, manual warm conditioning between brake stops					
9.2	486	386	10.2	406	335
11.2	432	331	12.2	591	525
Average6.3kN	812,0	711,5	Average	2024,0	1955,3
Average7.5kN	494,5	401,0	Average	1682,0	1614,0
Average7.5kN (warm)	459,0	358,5	Average	498,5	430,0

Table 18. Results for brake block C333 at braking at snow conditions 100 km/h, 6.3 kN. Average value and standard deviation of column data are given in two last rows.

run	s_1 [m]	t_1 [s]	s_2 [m]	t_2 [s]	$\Delta t_{1\to 2}$ [s]	Δs_μ [m]	Δt_μ [s]	Δs_{acc} [m]	Δt_{acc} [s]	Δs_{acc}^{REF} [m]	Δt_{acc}^{REF} [s]	
1	523	33	429	29	3,4	120	5	102	4	120	5	
3	525	33	418	29	3,9	72	3	65	2	109	4	
5	936	49	836	45	3,6	533	21	539	21	545	21	
7	1264	63	1163	60	3,6	848	33	864	34	870	34	
avg	812	44	712	41	3,6	393	15	393	15	411	16	
std	358	15	358	15	0,2	367	14	381	15	367	15	

9.4 Analysis of progression of coefficient of friction

Previous sections on winter brake performance have shown that the coefficient of friction evolves from

1) a state with low friction, where the friction is dominated by contact between ice or snow on brake block and wheel tread, into
2) a transition state with increasing friction caused by increased contact also between brake block friction material and the tread, and, finally,
3) a state with high friction dominated by direct contact between friction material and wheel tread.

In the following have this been studied in detail by investigating the time from onset of braking normal force, until specific friction levels are surpassed for the chosen levels μ_a = 0,03, μ_a = 0,05, μ_a = 0,1, μ_a = 0,15, μ_a = 0,2, μ_a = 0,25, and μ_a = 0,3. Detailed information on the time to reach different friction levels can be found in Appendix D.

In Figure 14 and Figure 15 results for brake blocks J822 and C333 respectively are shown with the time to reach friction level 0,05 in the top row, with braking from 100 km/h at left and 70 km/h at right, and in the row below the time to *further increase* the friction level from 0,05 up to 0,25.

The lower of these two friction values is chosen since ice sliding towards steel has a friction level lower than this, say below 0,03, and the higher level, 0,25 is chosen since it is near the lowest friction found at the reference braking, see Figure 6 and Figure 7. One could here note that block C333 has a somewhat higher average friction at reference conditions than J822, with values between 0,32 and 0,36 as compared to 0,25 to 0,27 at 70 and 100 km/h, which could motivate the use of different friction values for the high setting. However, such a choice would not change the below conclusions more than marginally.

9.4.1 Ice conditions, 100 km/h

For testing with ice on brake blocks it is for testing at 100 km/h with brake blocks J822 found that it takes between 4 and 12 s to reach a friction value 0,05, which can be contrasted with the result for block C333 with between 5 and 20 s. For block J822 there are no information that points towards a shorter time for a higher braking force, whereas for block C333, such a trend is evident. Somewhat short times are found for 7 kN than for 6,3 kN, and a more substantial drop is found when increasing the force to 9.23 kN. Note however, that the statistical basis for these conclusions is weak.

When studying the time for the coefficient of friction to increase from the low friction value to a high value, a very different picture emerges: brake block J822 shows times between 4 s for the case with the high force 9.23 kN, to registered values between 18 and 42 s for 6,3 kN, where two of the stops can be noted not to reach this friction level at all during the braking event. Brake block C333 on the other hand show a time for transition from 0,05 to 0,25 of between 3 and 6 s, irrespectively of the braking force.

This could be interpreted as once the completely iced contact surface of the C333 brake block starts to transform into partial contact between the friction material and the wheel, it is a fast process until almost the complete area is rendered ice free, and the friction value becomes high. For brake block J822 at the lower force level 7,5 kN, the interpretation would be that the transition process from completely ice covered contact surface to a full frictional material contact with wheel is a slow process, if it at all reaches a state of full contact between friction material and wheel tread. Indicatively, based on one single test, the transition is substantially faster, about 4 s as compared to more than 18 s, for the higher braking force 9,23 kN than for the lower force level of 7,5 kN.

9.4.2 Snow conditions, 100 km/h

Results for J822 at testing with snow on wheel and on brake blocks again show very mixed results as it takes between 0 and 25 s to reach 0,05 friction. Stops number 1, 5, 9 all show very short times to reach this value, and these can be identified as stops being performed at initially ice / snow free conditions, since brake blocks were de-iced after runs 4 and 8, see Table 15. The remaining stops, number 3, 7 and 11 have initiation times of between 12 and 26 s. These results indicate that the J822 is very sensitive to ice / snow conditions of brake blocks prior to the actual tests. Tests with brake block C333 show times to initiation of friction (i.e. reaching 0,05) that all are below 1 s, with no such history effects.

When studying the time for the coefficient to increase from the low friction value to the high value: brake block J822 is able to reach the high value of 0,25 for only two of the stops (number 9 and 11), whereas for the remaining ones 0,25 is not reached at all. Brake block C333 shows times for transition from 0,05 to 0,25 below 6 s, except for stops 5 and 7 with 21 and 34 s respectively at 6,3 kN braking force.

The results for the two snow braking stops at 7,5 kN are very similar to the ones at 6,3 kN, if the same 50 km/h condition braking between winter stops are used. However, only tested for C333, if a more powerful condition braking of 120 km/h is used prior to testing, much shorter transition times, with friction going from 0,05 to 0,25 is found, with times of below 2 s.

9.4.3 Ice conditions, 70 km/h

Braking performance for block J822 is very poor for the condition with ice on the friction surface. This is reflected in both the time to initiation of friction of between 18 and 37 s and that the higher friction value of 0,25 is never reached during a stop.

The braking performance of block C333 is also very poor, with registered times to initiation between 40 and 105 s, and the fact that the low friction value 0,05 is never reached for several of the stops. The transition from the chosen low friction (0,05) to high friction (0,25) is found merely for two of the stops, where the stop with a higher braking force shows a transition time of 5 s, which is similar to the ones found at 100 km/h.

9.4.4 Snow conditions, 70 km/h

Braking performance for block J822 is poor for the condition with snow on wheel and blocks. However, for two of the tests for which the blocks had been de-iced prior to tests, very short times to initiation of friction is found, whereas the rest have between 18 and 57 s. However, only two of the stops reach a high friction value of 0,25 (after 23 and 29 s).

For brake block C333, poor braking performance is also generally found, which is reflected in that none of the tests with standard conditioning stops (using 50 km/h in-between winter brake tests) reach the higher friction value 0,25 during braking. However, when using “warm conditioning”, with condition braking from 120 km/h between winter stops, both the time to initiation of friction (reaching friction 0,05) and the transition time to go from 0,05 to 0,25 are lower (both less than 10 s), indicating that having completely clean surfaces can be important for braking performance also from low speed.

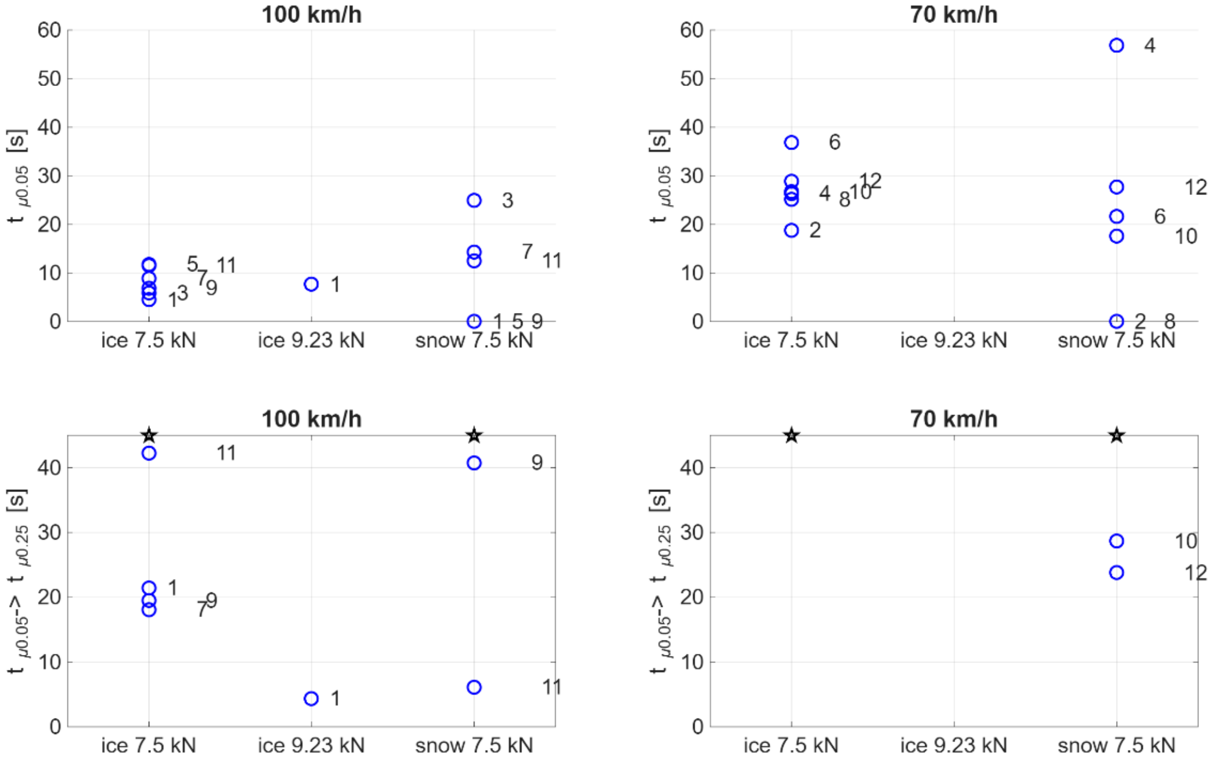


Figure 14 Block J822: time required to reach friction level 0,05 (top row) and time required go from friction level 0,05 to 0,25 (bottom row). Numbers relate to run numbers in previous sections. A pentagram at top indicates that the friction level was never reached.

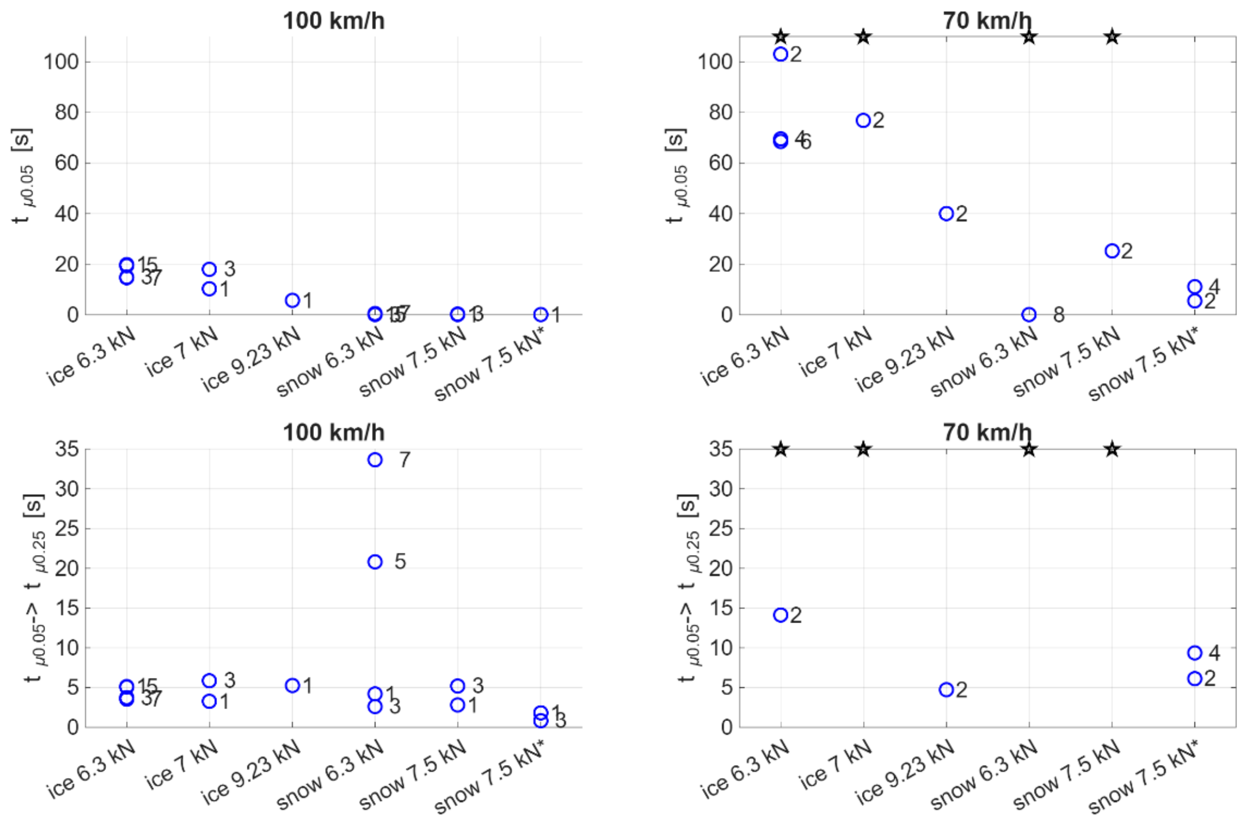


Figure 15 Block C333: time required to reach friction level 0,05 (top row) and time required go from friction level 0,05 to 0,25 (bottom row). Note that snow 7,5 kN indicates that the wheel and blocks were completely ice / snow free prior to test as a result of dry 120 km/h stop braking prior to snow testing. Numbers relate to run numbers in previous sections. A pentagram at top indicates that the friction level was never reached.*

9.5 Simulated temperatures in brake block surface and wheel tread over a wagon brake conditioning cycle

The employed thermal model and results from these numerical simulations are shown in Appendix E.

The simulation indicates a significant difference between J822 and C333 when it comes to temperatures during braking. Based on a thermal model that have been tuned by measured brake block temperatures at previously reported reference stops, it is found when simulating condition braking of a train in real operation that

1) the C333 block always has a higher or similar temperature in the friction surface, than on the wheel tread, and
2) the J822 block had periods, after brake applications, during cooling, when the brake block surface temperature < -5 º AND wheel tread temperature > +5 ºC. It is presumed that ice might build-up / be deposited on the J822 friction surface under these conditions when
    a) the wheel melts snow into water that can,
    b) further distribute / splash around the wheel and
    c) freeze onto the cold brake block.

This corresponds to the observations from real operation in temperatures ≲ -7 ºC and snow drift.

The calculations thus indicate a propensity for ice to deposit on J822 brake blocks and thus also a higher need for exercising of J822, which also corresponds to reality. No such propensity is found for blocks C333.

10 Conclusions from Becorit winter brake tests

Testing has been performed at

1) lower temperatures than according to UIC 541-4, Test Program, A5_a,
2) at relevant low application forces, axle loads and brake block configuration 1 x Bgu, that corresponds to unladen wagons in use, but with some few tests at higher application forces,
3) with brake applications at lower speeds, 70 km/h and 100 km/h, as typically applied in real operation, compared to 100 km/h and 120 km/h in UIC 541-4,
4) with ice on brake block contact surfaces (as observed in real operations), and
5) snow testing similar as UIC 541-4, Test Program, A5_a, but with
6) a lower speed of condition brake stops between winter test stops, using 50 km/h instead of 120 km/h.

Conclusions:

1) It is generally found that higher application forces, results in shorter braking distances. It shall be noted that when the application force is increased from 6,3 kN to 9,24 kN, which corresponds to a slightly loaded K block wagon, or an unladen wagon with LL blocks, then a significant decrease in brake distance.
2) When testing with ice on brake block friction surfaces it is found that
    a) this leads to extremely long braking distances for both tested brake block types, partially because of the very low initial friction when ice/water is transferred to the wheel,
    b) it results in similar braking distances when braking from 70 km/h, as when braking from 100 km/h,
    c) for block J822, when braking from 100 km/h, the ice layer suddenly starts to break-up and the coefficient of friction slowly increases towards higher values,
    d) for block C333, when braking from 100 km/h, the ice, similarly and suddenly starts to break up, after which the coefficient of friction rapidly increases towards a high value during some five seconds, and
    e) block J822 is sensitive to history effects (from previous brake cycle), with consecutively increasing braking distances as snow and ice remain from previous tests on contact surfaces and in the notch of the block, whereas C333 is not, or less, sensitive.
3) In addition to the above conclusions that are directly related to measured quantities, thermal simulations were performed that could assist in explaining the presence of ice on the contact surfaces of J822 brake blocks in service, and that no similar effect can be found for brake blocks of type C333, which normally are ice-free in normal operation.

4) When testing with snow being sprayed on wheel and on brake block it is found that
    a) brake block J822 shows substantially prolonged braking distances, again with clear history effects from previous stops, whereas block C333 shows a minor increase in distance for early braking tests (that are within a 15 % prolongation required for approval in UIC 541-4), but that show history effects after several stops at 6,3 kN,
    b) similar braking or longer braking distances are found when braking from 70 km/h as compared to 100 km/h, and
    c) short braking distances are found when for block C333 at both 100 km/h and 70 km/h when performing brake tests with enhanced condition braking from 120 km/h between snow tests (as used in UIC 541-4, Test Program, A5_a) instead of the regularly used 50 km/h.

11 Post Scriptum - Way forward

The property of this chapter is that it is not a directly generic part of the Project report as such. It seems evident to the Project that the reasoning and outcome of the investigations made need to be set into its context. Further, the context cannot be regarded as static. It is clear for the reader that the Project has a narrow scope, but at the mean time that the conclusions are self-standing but nevertheless would benefit from continued and in some details of necessary additional investigation and more tests. So, the following discussion is, not looking backwards or referring to the present – it is heading for the future.

The Project therefore completes the report by discussing the results within some directly concerned and relevant topic areas. The Project has identified the following topics as appropriate and connected to the Project results:

- Further testing and analysis
- Standardisation
- Legal framework

11.1 Further testing and analysis

As stated above it is necessary to further investigate the test results and perform additional testing and analysis in order to identify improved criteria for winter braking properties.

1) For future testing requirements should include testing in the most critical winter condition for which the brake blocks shall be certified in, i.e., configurations (1 x Bg, 2 x Bg, 1 x Bgu and 2 x Bgu), block shoe forces, axle load and wheel diameter.

2) In test bench it is of importance to replicate conditions that influence the braking properties. Further work will be needed to clarify the hypothesis that certain block types can accumulate an ice coating that strongly affects braking performance. The factors that have influence on the winter braking properties should be determined, e.g.
    - ambient, brake block and wheel tread temperatures,
    - snow drift, both in real operation and in test bench.
    - speed,
    - braking effort (force and time),
    - operating cycle including time and conditions in between brake application,
    - time until the ice layer becomes so thick that it affects the next braking effort,
    - the possibilities and procedures for building up ice layers on the friction surface of the brake block in a similar way at bench tests, as in real operation,
    - influence of thermal properties of the CBBs,

- the influence of having build-up of snow and ice on the wheel tread in the test bench,
- etc.

3) Ice layer building-up process and measurements, both in real operation and in test bench, need to be carried out in order to ensure that the bench testing procedure is relevant. The purpose is to identify thickness of the ice layers that occurs in real operation and identify the effects in bench testing. This can partly be identified with numerical simulation of wheel and block temperatures and hypothesis on ice deposition on blocks in order to reduce the checks in real operation.
4) Identification of influence of operational procedures such as exercising (braking) of CBBs, warm braking (braking with traction, see Annex 1), standstill application of brakes before departure, etc. Here it's of importance to compare and evaluate procedures from operation and bench test in order to identify suitable and powerful recommendations.
5) Identify an operation cycle for the test bench that can demonstrate acceptable or non-acceptable braking properties in winter conditions.

Once knowledge has been obtained, the requirements for winter braking properties can be revised. It shall be noted that test in real operation is difficult and uncertain to perform. Previous experiences from UIC line testing and from testing by Transportstyrelsen show that the conditions at test campaigns will show large spread in e.g. temperatures and levels of snow drift. To perform line tests for proving winter braking properties of brake blocks under specifically defined winter conditions, as detailed in a standard, thus becomes difficult (or impossible), time consuming and expensive, and motivates why winter testing for brake block *certification* should be performed only under *controlled winter conditions*. Therefore, should the end target be to design a bench test program that can establish reliable and safe winter properties for brake blocks. This requires further numerical simulations, checks or tests of brake blocks in real operation and further bench tests.

We are fully aware that there are many operational conditions, in addition to winter conditions, that must be taken into account for composite brake blocks, for example how the friction between blocks and wheels is affected by a drag brake, and the risk of wheel failure and derailment, etc. Therefore, CBBs must be managed with a holistic view. However, our focus has been limited to winter properties.

In conclusion we invite the Commission, the Agency, UIC and any other concerned – NSAs, industry representatives, Universities, laboratories – to take the baton and initiative to continue the way forward towards reliable use of brake blocks during winter conditions.

11.2 Standardisation

1) Legislation and standards for composite brake blocks are primarily set in the Directive (EU) 2016/797 [Ref. 1] and then further detailed and transformed into Commission Regulations, mainly WAG TSI [Ref. 2] and Noise TSI [Ref. 3]. Further, these latter regulations refer to the UIC Leaflets and European Standards, setting requirements or recommendation for design and usage, in this case UIC 541-4 [Ref. 5] and EN 16452 [Ref. 11]. These rules and recommendations are mandating these blocks for noise reduction in freight, setting performance (friction, wear, winter use) and testing criteria (K, LL types). And finally, ERADIS[12], where the EC declaration of conformity of

[12] European Railway Agency Database of Interoperability and Safety

interoperability constituents can be found with the limits for use for a certain CBB. Following this reasoning, it is established that the test specifications referred to in the UIC leaflets and EN Standard and thus applicable could be altered into ones which correspond with and reflect the final usage conditions.

2) It is for the benefit of safety and reliable railway traffic that the results of this project could be taken under serious consideration. Further investigation would enhance, validate and strengthen the project thesis. This should be a natural and hopefully immediate next step for the UIC and the Technical Committee, CEN/TC 256 - Railway applications, and the Drafting Committee, CEN/TC 256/SC 3/WG 47 – Braking, respectively to take on and further initiate a development project based on this report.

11.3 Legal framework

1) As mentioned above the legislation in place is based on certain programmes of braking tests. These programmes constitute of certain parameters, specifications. It has been concluded by this project that the reality based conditions (specifications) are not, or at least, sufficiently reflected and formulated in the programmes. As it is strongly connected to the rationale above regarding the development of both the UIC code(s) and the relevant EN standard, the Project finds that it is both logic and necessary for the Commission and the Agency to engage in the adaptation of the UIC code and EN standard in line with the project conclusions. When such action regarding the legal prerequisites is taken onboard in parallel with test programme development at UIC and the CEN respective committees and working groups the adjustments to what the Project is referring to in its conclusions would pave the way to a revision of the relevant legislation to be in force and applicable with the shortest delay possible, to the benefit of safety and traffic economy.

2) It is to be noted that the test programme is designed for “winter conditions”. It is further to be noted that in the applicable legislation there are four (4!...) different concepts for this, *“winter conditions” – “severe winter conditions” – “Nordic winter conditions” – “Extreme winter conditions”*. To once again be noted, there is no formal definition of what “winter conditions” are, much less regarding the two other concepts. As it is not within the project scope to define this concept, it still remains as a both technical and legal conceptual flaw. Action needs to clarify and complement the legislation as for the UIC code(s) and eventually the EN standard.

3) Another issue of significant importance is the current specific case where Sweden, as Finland, is exempted from the use of composite brake blocks. The concept of quieter routes shall therefore not apply on the Swedish networks, and similar for Finnish networks, due to uncertainties related to the operation in winter conditions with composite brake blocks until 31 December 2032.
As clearly indicated by the test results of this project, the stated reasons for the exception, i.e. *“…the uncertainties related to the operation in severe winter conditions with composite brake blocks…”*, are still valid and the project conclusions establishes sustainable and viable reasons and arguments to prolong this term. The project has clearly showed that there are no definite changes since the exemption was given regarding the uncertainties of the composite brake blocks braking capacities. It is not within the scope of this Project to nor examine nor suggest a concrete proposal, it is nevertheless of directly consistent and prevailing reasons, based on facts, to consider a reasonable term for prolongation of the exemption.

The Project therefore suggests that a working group is established to draft the proposed alterations in the UIC code and EN standard respectively including to present a relevant concept concerning conditions during winter. The Project would be at their disposal.

12 Appendices

13 Annexes

14 References

[Ref. 1] Directive (EU) 2016/797 of the European parliament and of the council of 11 May 2016 on the interoperability of the rail system within the European Union
Amended by: Directive (EU) 2020/700 of the European Parliament and of the Council of 25 May 2020

[Ref. 2] Commission regulation (EU) No 321/2013 of 13 March 2013 concerning the technical specification for interoperability relating to the subsystem ‘rolling stock — freight wagons’ of the rail system in the European Union
Amended by:
Commission regulation (EU) No 1236/2013 of 2 December 2013
Commission regulation (EU) 2015/924 of 8 June 2015
Commission implementing regulation (EU) 2019/776 of 16 May 2019
Commission implementing regulation (EU) 2020/387 of 9 March 2020
Commission implementing regulation (EU) 2023/1694 of 10 August 2023
Commission implementing regulation (EU) 2025/2064 of 14 October 2025
(TSI WAG)

[Ref. 3] Commission regulation (EU) No 1304/2014 of 26 November 2014 on the technical specification for interoperability relating to the subsystem 'rolling stock - noise' amending Decision 2008/232/EC
Amended by:
Commission Implementing Regulation (EU) 2019/774 of 16 May 2019
Commission Implementing Regulation (EU) 2023/1694 of 10 August
(TSI Noise)

[Ref. 4] UIC 541-4. Composite brake blocks - General conditions for certification and use 6th edition. November 2020. Issued by UIC.

[Ref. 5] IRS 50548:2022, Ed2: Brakes – Requirements for friction test benches for the international certification of brake pads and brake blocks
Issued by UIC.

[Ref. 6] EC Declaration of conformity of interoperability constituents.
Document ID number: IT/00002401890641/2021/000002
Description: Sintered brake blocks in mix C333, 1 x Bgu configuration 920mm wheel
Issued by CoFren s.r.l.
With attached document: NoBo File. Doc. No: RVI_004 13693.01. Rev. 1. Issued by IIS Cert S.r.l.
Source: https://eradis.era.europa.eu/

[Ref. 7] EC Declaration of conformity of interoperability constituents.
Document ID number: DE/000DE811198586/2024/000008
Description: Friction element for wheel tread brakes – Jurid 822
Issued by Federal Mogul Bremsbelag GmbH
Source: https://eradis.era.europa.eu/

[Ref. 8] EC Declaration of conformity of interoperability constituents.
Document ID number: DE/00000129273865/2021/000009
Description: Problock J822 1 x Bgu - Composite friction element for wheel tread brakes according to TSI WAG, in 1 x Bgu configuration, for nominal wheel diameter 920 mm
Issued by Knorr-Bremse Systeme für Schienenfahrzeuge GmbH
Source: https://eradis.era.europa.eu/

[Ref. 9] UIC B 126 / RP 37. Braking Questions Winter properties of composite brake blocks.
Issued by UIC.

[Ref. 10] Report. Measurement of thermal conductivity
Reference: O100728-1340928
Date: 2026-01-09
Issued by RISE Research Institutes of Sweden AB

[Ref. 11] EN 16452:2015+A1:2019. Railway applications Braking - Brake blocks